

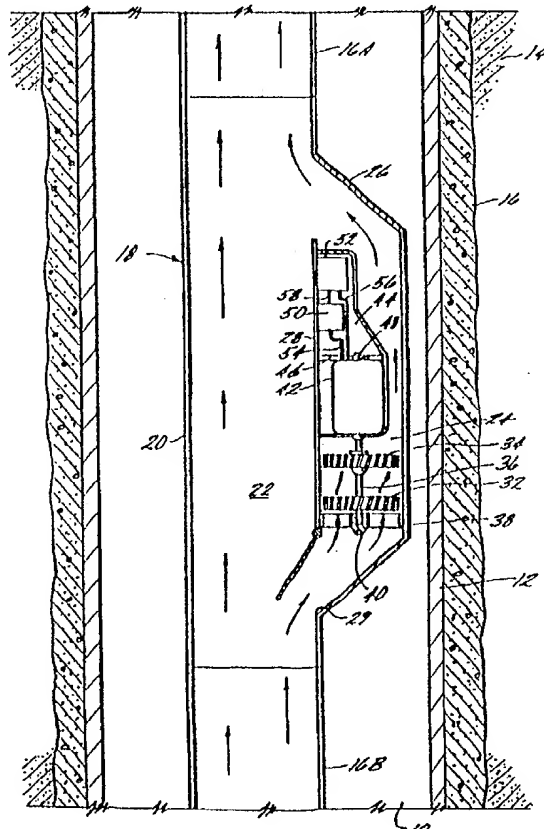
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : E21B 41/00		A2	(11) International Publication Number: WO 97/01018
			(43) International Publication Date: 9 January 1997 (09.01.97)
(21) International Application Number: PCT/US96/10546			(81) Designated States: AU, CA, DE, DK, GB, NO. Published <i>Without international search report and to be republished upon receipt of that report.</i>
(22) International Filing Date: 19 June 1996 (19.06.96)			
(30) Priority Data: 60/000,469 23 June 1995 (23.06.95) US			
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(54) Title: DOWNHOLE APPARATUS FOR GENERATING ELECTRICAL POWER IN A WELL**(57) Abstract**

Electrical generating apparatus is provided which connects to the production tubing. In a preferred embodiment, this apparatus includes a housing having a primary flow passageway in communication with the production tubing. The housing also includes a laterally displaced side passageway communicating with the primary flow passageway such that production fluid passes upwardly towards the surface through the primary and side passageways. A flow diverter may be positioned in the housing to divert a variable amount of production fluid from the production tubing and into the side passageway. In accordance with an important feature of this invention, an electrical generator is located at least partially in or along the side passageway. The electrical generator generates electricity through the interaction of the flowing production fluid.



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DOWNHOLE APPARATUS FOR GENERATING
ELECTRICAL POWER IN A WELL

Background of the Invention:

This invention relates to apparatus and methods for providing electrical power to electrical circuits located in a well. More particularly, this invention relates to downhole apparatus and methods for producing electrical power in oil and gas production wells wherein the primary wellbore passage is maintained free of obstruction.

The control of oil and gas production wells constitutes an important and on-going concern of the petroleum industry. Production well control has become particularly important and more complex in view of the industry wide recognition that wells having multiple branches (i.e., multilateral wells) will be increasingly important and commonplace. Such multilateral wells include discrete production zones which produce fluid in either common or discrete production tubing. In either case, there is a need for controlling zone production, isolating specific zones and otherwise monitoring each zone in a particular well. As a result, the methods and apparatus for controlling wells are growing more complex and in particular, there is an ever increasing need for downhole control systems which include downhole computerized modules employing downhole computers (e.g., microprocessors) for commanding downhole tools such as packers, sliding sleeves and valves. An example of such a sophisticated downhole

-2-

control system is disclosed in U.S. Patent Application Serial No. 08/385,992 filed February 9, 1995, which is assigned to the assignee hereof and incorporated herein by reference. This application discloses downhole sensors, downhole electromechanical devices and downhole computerized control electronics whereby the control electronics automatically control the electromechanical devices based on input from the downhole sensors. Thus, using the downhole sensors, the downhole computerized control system will monitor actual downhole parameters (such as pressure, temperature, flow, gas influx, etc.) and automatically execute control instructions when the monitored downhole parameters are outside a selected operating range (e.g., indicating an unsafe condition). The automatic control instructions will then cause an electromechanical control device (such as a valve) to actuate a suitable tool (for example, actuate a sliding sleeve or packer, or close a valve or start/stop a pump or other fluid flow device).

It will be appreciated that the above-described well control system as well as other well control systems utilize downhole devices and circuits which require electrical power. However, presently known methods of supplying or generating electricity downhole each suffers from a host of problems and deficiencies.

One manner of providing electricity downhole in a well includes lowering a tool on a wireline and conducting energizing electricity through one or more conductors in the wireline from the surface to the tool when positioned downhole. This technique is not always desirable because it is relatively complex in that it requires the wireline to be passed through the wellhead closure equipment at the mouth of the well. This can create safety problems. Furthermore, at least in deep wells, there can be significant energy loss caused by the resistance or impedance of a long wireline conductor.

Another way to provide electricity to downhole electrical circuits utilizes batteries housed within the electrical circuits in the downhole assembly. For example, lithium-thionyl-chloride batteries have been used with downhole tools. A shortcoming of batteries, however, is that they cannot provide moderate (and higher) amounts of electrical energy (e.g., 30 kilowatt-hours) at the elevated temperatures encountered in

-3-

petroleum and geothermal wells. Batteries are also extremely dangerous. Still another problem with batteries are their relatively short life whereupon the batteries need to be replaced and/or recharged.

Because of the shortcomings of power derived either from wireline or battery sources, suggestions have been made to provide a downhole mechanism which continuously generates and supplies electricity. For example, U.S. Patent 4,805,407 to Buchanan discloses a downhole electrical generator/power supply which includes a housing in which a primary fuel source, a Stirling cycle engine, and a linear alternator are disposed. The primary fuel source includes a radioisotope which, by its radioactive decay, provides heat to operate the Stirling engine which in turn drives the linear alternator to provide a suitable electrical output for use by the circuit of the downhole tool. U.S. Patent 5,202,194 to VanBerg Jr. discloses a downhole power supply comprised of a fuel cell.

U.S. Patent Nos. 3,970,877 ('877) and 4,518,888 ('888) both relate to the use of piezoelectric techniques for generating small electric currents. The '888 patent generates electrical energy downhole (in the drillstring) by the use of a piezoelectric device stored in the drill collar which converts vibrational energy from the drillstring into electrical energy. The piezoelectric device is in the form of a stack of piezoelectric elements arranged in an electrically additive configuration. The '877 patent describes a method of power generation used in a drilling operation wherein a piezoelectric material is responsive to turbulence in the mud flowing past the piezoelectric material. The vibrations resulting from the turbulent flow of the mud past the piezoelectric material will be converted into an electrical output. In addition to a piezoelectric material, the '877 patent also discloses the use of a fixed coil with a magnetic core freely movable relative to the coil and attached to the inner surface of a flexible disk which will also be actuated by the flowing mud for generation of electrical energy.

U.S. Patent 3,666,030 ('030) discloses a stressed spring or other form of stored energy which is carried downhole and is then converted to electrical energy by causing relative motion between a permanent magnet and coil and some other structure which is urged into movement by the compressed spring. In the '030 patent, the energizing

-4-

source comprises a housing which is adapted to traverse a borehole. A magnetic coil is positioned within the housing and the storage means for storing energy (i.e., spring) is also positioned in the housing. A release mechanism located in the housing releases the stored energy at the proper moment downhole so that the electrical energy can be generated.

U.S. Patent 3,342,267 ('267) to Cotter et al discloses downhole production tubing including an electric generator which is energized by a turbine for providing electricity to a coiled heater which is also disposed in the production tubing. The turbine rotates upon the upward flow of fluids in the production tubing. In FIGURE 2 of the '267 patent, a primary production tubing is shown at 12, a coiled heater is shown at 24 and downstream from the coiled heater is a series of rotatable turbines 26. Disposed laterally from production turbine 12 is a side compartment 38 which houses the electrical generator 20. During operation, production fluid flows upwardly through production tubing 12 thereby rotating turbines 26 which in turn, through a series of gearings, will rotate generator 20 in the side compartment 38 and thereby generate electricity to power the heating coil 24.

The numerous attempts at generating electricity downhole in a well as disclosed in the aforementioned patents all suffer from one or more drawbacks and problems including, for example, environmental and safety concerns (e.g., patent 4,805,407)), high expense and complexity (e.g., patent 5,202,194), inability to generate high or sustained levels of power (e.g., patents 3,666,030; 3,970,877; 4,518,888) and causing obstructions within the production tubing (e.g., patent 3,342,267). This latter problem, that of obstructing the production tubing, poses a serious drawback to many prior art schemes. In the '267 patent, for example, the turbine blades are positioned in the primary production tubing and thus would preclude unobstructed production as is required, particularly so as to enable entry of completion equipment and other objects into the production tubing. Thus, the turbo generator of the '267 patent would not allow for the downhole introduction of instruments, tools and other completion devices due to the presence of turbines.

-5-

Such obstruction problems are also an important reason why well known turbo generators used in generating electricity during drilling operations (e.g., for powering MWD equipment) would be problematic when used in a production well. Examples of patents describing downhole turbo generators used during drilling include patents
5 3,036,645 and 4,647,853.

Summary of the Invention:

The above-described and other drawbacks and deficiencies of the prior art are overcome or alleviated by the downhole electrical generating apparatus and methods of the present invention. In accordance with the present invention, electrical generating
10 apparatus is provided which connects to the production tubing. This apparatus includes a housing having a primary flow passageway in communication with the production tubing. In a first embodiment of this invention, the housing also includes a laterally displaced side passageway communicating with the primary flow passageway such that production fluid passes upwardly towards the surface through the primary and side
15 passageways. A flow diverter may be positioned in the housing to divert a variable amount of production fluid from the production tubing and into the side passageway. Alternatively, production fluid may enter the side passageway from the annulus defined by the production tubing and the borehole wall or casing.

In accordance with an important feature of this invention, an electrical
20 generating device is located in or along the side passageway. The electrical generating device generates electricity through the interaction of the flowing production fluid. In a first embodiment of this invention, a turbine or the like is operatively connected within the side passageway for movement in response to fluid flowing through the side passageway. A generator is also positioned in the side passageway and is operatively
25 connected to the turbine for generating electricity in response to movement by the turbine. In a second embodiment of this invention, a magnetic field is positioned in the side passageway with the magnetic field being movable in response to fluid flowing the

-6-

side passageway (such as an oscillating magnetic reed enclosed by a coil). An electrical energy converter in the side passageway converts the AC power created by the movable magnetic field into DC electrical energy.

5 In a third embodiment of this invention, a movable magnetic field within the side passageway is effected by positioning magnets on a movable bladder which is sandwiched between a pair of coils. Fluid is directed through the bladder such that the magnets move with respect to the coils thereby generating electricity. Preferably, a turbulence enhancer is positioned upstream of the bladder to cause a turbulent and constant movement of the fluid within the bladder. In a fourth embodiment, the
10 electrical generating device in the side passageway constitutes a piezoelectric power supply wherein a piezoelectric assembly generates electrical power in response to fluid flow.

In accordance with another embodiment of this invention, pressure waves are delivered downhole through a column of fluid to actuate an electrical generating device
15 to thereby generate electricity. In one such embodiment, the pressure waves travel through the production tubing and cause a laterally mounted spring actuated magnet/coil assembly to move in a reciprocal motion and thus generate electricity. In another such embodiment, the pressure waves travel downwardly through a separate control line to actuate the laterally mounted or annulus mounted magnet/coil assembly
20 to reciprocate and generate power.

In still another embodiment of this invention, various electrical energy generating devices are positioned in the annulus adjacent the production tubing and generate electricity in response to fluid flowing either from the production tubing or within the annulus itself. In one such embodiment, the electrical generating device
25 comprises a turbine rotatably mounted about the outer circumference of the production tubing. Attached to the turbine is one or more magnets. Also attached to the outer circumference of the production tubing and in spaced, facing relation to the magnet is a coil. During use, production fluid flowing from the annulus or from within the

-7-

production tubing out to the annulus, will flow past the turbine causing the turbine and attached magnet(s) to freely rotate about the tubing. The rotating magnet will interact with the coil in a known manner to generate electricity.

5 Preferably, in each of the foregoing embodiments, a rechargeable battery may also be present in the side passageway with the electrical generator being operatively connected to the battery for electrically charging the battery. As a result, an electrical circuit such as a downhole computer can be provided with electricity either directly from the generator or from the battery. Since many of the electrical generator techniques of this invention necessitate the flow of production fluid, provision of a
10 battery is particularly important for those periods where the flow of production fluids has halted or significantly slowed.

A particularly preferred rechargeable battery for use in the downhole power generation apparatus of this invention is a lithium power cell (LPC) using polymer electrolytes. Also believed to be preferred is a rechargeable battery which incorporates
15 integrated circuit technology for maximizing battery life.

The downhole electrical generating methods and apparatus of the present invention provide many features and advantages over prior art techniques. One important feature is that the components which generate the electricity are outside of the primary passageway defined by the production tubing. As a result, the present
20 invention does not in any way obstruct the production tubing (as does for example, the turbo generator of patent 3,342,267). This means that completion equipment, coiled tubing and other objects may be freely introduced downhole. The present invention also provides environmentally acceptable, relatively low cost processes and apparatus for downhole electrical generation.

25 The above-discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

-8-

Brief Description of the Drawings:

Referring now to the drawings, wherein like elements are numbered alike in the several FIGURES:

5 FIGURE 1 is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention utilizing a turbine located in a side passageway;

FIGURE 1A is a cross-sectional elevation view of a downhole power generating apparatus, similar to FIGURE 1, but utilizing an alternative fluid diverter;

10 FIGURE 2 is a cross-sectional elevation view of a downhole power generating apparatus, similar to FIGURE 1, but being responsive to fluid flow from the annulus;

FIGURE 3 is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention utilizing an oscillating reed;

15 FIGURES 4A and 4B are cross-sectional elevation views of related downhole power generating apparatuses in accordance with this invention utilizing a movable bladder associated with a magnet/coil assembly for generating electrical power downhole;

FIGURE 5 is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention utilizing a piezoelectric generating device located in a side passageway;

20 FIGURE 6 is an electrical schematic of the circuitry involved in the embodiment of FIGURE 5 for converting signals from the piezoelectric device to electricity and/or stored power;

25 FIGURE 7A is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention wherein a spring actuated magnetic/coil assembly generates power in response to pressure waves;

FIGURE 7B is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention wherein a spring actuated generator armature assembly generates power in response to pressure waves;

-9-

FIGURE 7C is a cross-sectional view of a device for producing pressure pulses;
FIGURE 7D is a cross-sectional view of an alternative device for producing pressure pulses;

5 FIGURE 8 is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention, similar to the power generating device of FIGURE 7, with the pressure waves being delivered via a separate control line;

FIGURE 9 is a cross-sectional elevation view of a downhole power generating apparatus in accordance with this invention utilizing a turbine positioned in the annulus between the production tubing and the casing or borehole wall;

10 FIGURES 10A through 10C are cross-sectional elevation views depicting a power generating apparatus located in the annulus between the production tubing and well casing which consists of a magnet/coil assembly rotatably mounted on the production tubing;

15 FIGURE 11 is a cross-sectional elevation view of a downhole power generating apparatus consisting of a piezoelectric or magnetic assembly positioned in the annulus between the production tubing and the casing or borehole wall; and

FIGURE 12 is a cross-sectional elevation view of a downhole power generating apparatus, similar to the embodiments of FIGURES 4A-4B, but with the movable bladder being positioned in the production tubing's primary passage.

20 Description of the Preferred Embodiment:

Referring first to FIGURE 1, a downhole electrical generating apparatus in accordance with a first embodiment of this invention is shown. FIGURE 1 more particularly depicts a production well 10 for producing oil, gas or the like. Well 10 is defined by well-known well casing 12 which is cemented or otherwise permanently positioned in earth 14 using an appropriate cement or the like 16. Well 10 has been completed in a known manner using production tubing with an upper section of production tubing being shown at 16A and a lower section of production tubing being shown at 16B. Attached between production tubing 16A and 16B, at an appropriate location, is the electrical power generating apparatus in accordance with the present

25

-10-

invention which is shown generally at 18. Power generating apparatus 18 comprises a housing 20 having a primary flow passageway 22 which communicates with and is generally in alignment with production tubing 16A and 16B. Housing 20 also includes a side passageway 24 which is laterally displaced from primary flow passageway 22.

5 Side passageway 24 is defined by a laterally extending section 26 of housing 20 and an interior dividing wall 28. Shown by the arrows, production fluids such as petroleum are produced from below electrical generating device 18 and travel upwardly through production tubing 16B into housing 20 whereupon the production fluid travels both through the primary passageway 22 and the side passageway 24. Upon reaching the
10 upper portion of side passageway 24, the production fluid again enters the primary passageway 22 and then travels on upwardly into the upper section of production tubing 16A.

The amount of fluid traveling into side passageway 24 may be controlled using a flow diverter 30 which is pivotally attached to wall 28. Flow diverter 30 may shut off
15 all fluid flow into side passageway 24 or in contrast, open up the fluid flow into side passageway 24 so as to divert a varying amount of fluid therethrough. Diverter 30 may be controlled from the surface using coil tubing or other tools.

In the first embodiment of FIGURE 1, the electrical generating means utilizes one or more turbines (in this case two turbines 32 and 34). Turbines 32, 34, are
20 mounted on a shaft 36. Shaft 36 is rotatably mounted in a lower mount 38 where a centrally located bearing 40 permits shaft 36 to freely rotate therein. The upper section of shaft 36 is mounted to a conventional electrical generator 42 such that rotation of shaft 36 will rotate so as to produce electricity in a known manner. In a preferred embodiment, generator 42 is positioned in a fluid tight chamber 44 so as to preclude the
25 adverse effects of the pressurized and high temperature production fluids flowing through side passageway 24. Shaft 36 terminates within chamber 44 at a support 46 which houses an upper bearing 48. Also located in chamber 44 is a rechargeable battery 50 and a computer or other device 52 which includes at least one circuit which requires electrical power. Electrical generator 42 communicates directly through a first
30 wire 54 to battery 50 and through a second wire 56 to computer 52. In turn,

-11-

rechargeable battery 50 communicates with computer 52 through a wire 58. As will be discussed, rechargeable battery 50 may comprise any conventional rechargeable battery which is adapted for high temperature operations. As mentioned, item 52 may comprise any device or group of devices which include at least one electrical circuit which is powered by the present invention. For example, item 52 may comprise a computer such as shown at 50 in FIGURE 6 of aforementioned U.S. Application S.N. 08/385,992. In this latter example, power source 66 as shown in FIGURE 6 of USSN. 08/385,992 could be constituted by either rechargeable battery 50 or electrical generator 42.

It will be appreciated that one or more of electrical generator 42, battery 50, computer 52 and any other component associated with the turbines may be located in another location (such as in the annulus) so long as these components do not block the primary passageway 22.

It will further be appreciated that the separation between primary flow passageway 22 and the electrical generating apparatus in side passageway 24 could be effected using a liner for separation as opposed to the more complex housing 20.

During operation, production fluid flowing upwardly through production tubing 16B is diverted by diverter 30 into side passageway 24 whereupon the fluid will rotate in a known manner turbines 32 and 34. Rotating turbines 32, 34 will cause shaft 36 to rotate which in turn, will provide the necessary rotation for the generation of electricity in generator 42. Electricity generated by generator 42 (which, if necessary, is converted from AC to DC using a known AC/DC converter) may be used either to directly power a circuit in item 52 and/or may be used to recharge battery 50. If item 52 is a computer, then the computer may be programmed to receive electrical power either directly from generator 42 or from battery 50. In some cases, it may be preferable that computer 52 only receive its power from battery 50. When fluid flow in production tubing 16B ceases, rechargeable battery 50 can supply, on a continuous or intermittent basis, power to computer 52. The amount of fluid flowing into side passageway 24 may be controlled by diverter 30 depending on the need for electricity and other relevant factors. It will be appreciated that computer 52 will communicate

-12-

with other downhole devices such as described in more detail in Application S.N.
08/385,992.

In FIGURE 1A, an alternative flow diverter means is shown wherein a flexible, tapered restriction 31 (which may be made from an high temperature elastomer or other appropriate material) is attached to the inner surface of primary passage 22 near the opening 29 to side passage 24. This flexible restriction 31 ensures fluid flow through lateral passage 24 as shown by the arrows. In addition, should a tool, coiled tubing or other object be required to pass through primary passage 22, restriction 31 will easily yield (deflect outwardly towards the inner walls of tubing 22) to the object. After the object has passed, the restriction 31 will recover to its original shape.

Referring to FIGURE 2, an electrical power generating device utilizing a turbine similar to FIGURE 1 is shown. The main difference between the embodiments of FIGURE 1 and FIGURE 2 is that in FIGURE 2, the turbine is actuated by production fluid flowing in from the annulus as opposed to flowing in from within the production tubing itself. More particularly, side passageway 24 is shown which includes turbine 32, 34 mounted on a shaft 36 which in turn is mounted to a generator 42. The generator communicates with an energy storage device 50 (battery) and associated electronics 52 as in FIGURE 1. Perforations 68 have been formed through the casing 12, cement 16 and formation 14 so as to allow production fluid (indicated by the arrows) to flow from the formation and into the annulus 10. These formation fluids travel upwardly through at least one opening 70 and into the side passageway 24 whereupon the fluid interacts with turbines 32, 34 causing the turbines to rotate and generate electricity in the same manner as was discussed in detail with regard to FIGURE 1. After passing through turbines 32, 34, the fluid continues to flow upwardly and into the primary flow passageway of production tubing 20. It will be appreciated that the alternative embodiment of FIGURE 2 may be utilized in those locations downhole where formation fluids are being produced at or near the power generating location as shown in FIGURE 2. Of course, the FIGURE 2 embodiment can also have an opening of the type shown at 29 in FIGURE 1 (with or without a flow diverter 30) so that turbines 32, 34 could be actuated from production fluid which both is flowing

-13-

upwardly through tubing 16 and which is flowing outwardly from the formation into annulus 10.

Turning now to FIGURE 3, a second embodiment of the power generating apparatus of the present invention is shown. This second embodiment is substantially similar to the first embodiment of FIGURES 1 and 2 with the primary difference being that rather than using the turbine based generator of FIGURE 1, the second embodiment utilizes an alternative power generating source wherein the movement of a magnetic field is used to create a magnetic flux for electrical power generation. This movable magnetic field is obtained using a reed or the like 72 which is mounted on a shaft 74 within lateral housing 26 using mount 76. Reed 72 comprises a permanent magnet which is rotatable (in a manner analogous to a propeller) relative to shaft 74. Lower portion 26 of side passageway 24 includes a coil 78 with reed 72 being positioned within coil 78. The north and south poles of reed 72 are positioned transverse to the cylindrically shaped coil 78 such that when reed rotates or oscillates, a magnetic flux will be induced on coil 78 in a known manner. Electrically communicating with coil 78 is a converter 80 which converts AC electrical output to DC electrical energy. As in the FIGURE 1 embodiment, converter 80 is connected directly to a rechargeable battery 50 and a computer or other device which incorporates an electrical circuit 52.

As discussed above, the change in the magnetic field induced in the coils 78 will generate the electrical power that will be rectified and stored in the rechargeable battery cell 50. One of the basic equations underlying this power generation technique (as well as the other techniques described herein which rely on a movable magnetic field) is:

$$dW(L,X) = I \cdot dL - FdX$$

where

W is the system energy;

L is the magnetic flux;

X is the displacement of the armature;

I is the electric current; and

F is the mechanical force.

-14-

It will be appreciated that the energy is constant and the magnetic flux is the link between the electrical force and the mechanical force.

During operation, production fluid travels upwardly from production tubing 16B into housing 20 whereupon the fluid travels both through the primary passageway 22 and is diverted by optional diverter 30 into the side passageway 24. The fluid flowing into side passageway 24 acts to oscillate or rotate reed 72 as shown by the arrows in FIGURE 3. The movement of reed 72 within the coil 78 creates a magnetic flux (e.g., a movable magnetic field) which is converted in a known manner to electricity. As in the FIGURE 1 embodiment, converter 80 may then directly provide electricity either to rechargeable battery 50 or to item 52.

Turning now to FIGURES 4A and 4B, in accordance with a third embodiment of the present invention, a movable magnetic field is created within the side passageway 24 using an expandable bladder 82 having one or more magnets 84 attached to the outer periphery thereof. On either side of magnets 84 are a pair of coils 86, 88. Coils 86, 88 are attached to the inner walls of side passageway 24. Preferably, a turbulence enhancer 90 which may consist of a plurality of appropriately spaced and contoured vanes, is positioned upstream of bladder 82 at the inlet to side passageway 24. Coils 86, 88 are in electrical communication with an electronics module 92 and rechargeable battery 94.

During operation, fluid flows upwardly through production tubing 16 and a portion of the fluid is diverted (using if desired, a diverter 30 as shown in FIGURE 1) into side passageway 24 where it is directed through turbulence enhancer 90 and into the flexible bladder 82. The turbulence enhancer 90 will cause the fluid to undergo a turbulent motion and thereby cause the flexible bladder 82 to undulate and move magnets 84 within the annular space defined between coils 86 and 88. As a result, a magnetic flux will be developed on coils 86 and 88 thereby producing electrical energy which will flow to electronics 92 and rechargeable battery 94 in a manner as described above with regard to the FIGURE 3 embodiment.

As mentioned, in the FIGURE 4A embodiment of this invention, the production flow within tubing 16 causes the bladder 82 to move and undulate and thereby produce

-15-

electricity. Alternatively, in the FIGURE 4B embodiment, production fluid from perforations 68 of the type described in FIGURE 2 are directed into the annulus and flow within side passageway 24 through an opening 70 and into bladder 82. It will be appreciated that the FIGURE 4B embodiment could also include an inlet to side passageway 24 from primary flow passageway 22 as in the FIGURE 4A embodiment.

Turning now to FIGURE 5, still another embodiment of this invention wherein an electrical generating device is positioned at least in part, within a side passageway is shown. In the FIGURE 5 embodiment, the electrical generating device comprises a stack of piezoelectric elements 90 which are connected to a power rectifier 92, voltage regulator 94, charge/power on switch 96 and rechargeable battery 98 as schematically shown in FIGURE 6. Piezoelectric elements 90 are composed of a low level force to electrical charge piezoelectric crystal or film. A vibration amplifier will convert the flow turbulence from within tubing 16 into a motion (e.g., vibration or stress) outside the tubing. The piezoelectric wafer stack is mounted with a motion generator to convert the movements into electrical charges. The power rectifier circuit 92 will process the electrical charges into an electrical direct current. The output voltage from rectifier 92 will be regulated via regulator 94 to create a signal compatible with the battery cells 98. The charge/power-on circuit 96 will determine if the battery cell 98 should be charged or if the battery pack should deliver power to the electronic circuit (such as item 52 in FIGURE 1). A dual battery pack (identified as "1" and "2" in element 98) is preferred such that one pack will deliver power to the electronics while the other pack is being recharged. As shown in FIGURE 5, the piezoelectric stack 90 may be actuated by movement of fluid flowing both within production tubing 16 as well as from the annulus 10 through the aforementioned perforation 68 and out of the formation. Piezoelectric stack 90 is composed of any one of several known materials including piezoelectric crystalline materials or polymeric films such as polyvinyl chloride film. Such known materials generate electrical power once a mechanical force such as vibration or stress is exerted onto the stack. In this case, the vibration or stress will be exerted onto the stack through the production fluid impacting upon the stack via the tubing wall 28.

-16-

While the foregoing embodiments of the present invention shown in FIGURES 1-6 generate electricity by the positioning of an electrical generating device in a lateral passageway and then generating electricity through the interaction of fluid being produced either from the formation into the annulus or from within the production tubing itself, in FIGURES 7A, 7B and 8, an alternative method of generating electricity will be described wherein pressure waves are sent downwardly through a suitable fluid so as to actuate a suitable power generation device. In the FIGURE 7A embodiment, this power generation device is again positioned in a lateral chamber 24 which is positioned outside of the primary flow passage. More particularly, the power generation device comprises a permanent magnet 100 which extends outwardly from a piston 102. Piston 102 sealingly engages a suitably sized cylinder 104 (via seal 106). A spring 107 is sandwiched between piston 106 and the interior base 108 of cylinder 104. Spring 107 surrounds magnet 100. It will be appreciated that when a force urges the upper surface 110 of piston 102 downwardly, spring 107 will be compressed such that when the force on surface 110 is removed, spring 107 will urge upwardly to place piston 102 into its normal position. Surrounding chamber 104 and positioned in facing alignment to the normal position of magnet 100 is a coil 112. Coil 112 in turn electrically communicates with an electronics and battery package 114 of the type described above with regard to the embodiments shown in FIGURES 1-5.

During operation, assuming that production fluid or other fluid is present within the primary passage 16, pressure waves indicated by the lines 115 are directed downwardly from the surface or from some other position downstream of side passageway 24 and impinge upon surface 110 of piston 102. The pressure waves are delivered over a selected intermittent and timed sequence such that piston 102 will be sequentially urged downwardly when impinged by a pressure wave. During the time period that the pressure wave has passed and before the next pressure wave impinges upon piston 102, spring 107 will urge piston 102 upwardly to its normal position. As a result, piston 102 will undergo a reciprocating upward and downward motion whereby magnet 100 will similarly reciprocate within the annular opening defined between coil 112. The result is a magnetic flux which will generate electricity in a known manner

-17-

and supply the electricity to the appropriate electronics and storage battery 114 as discussed above regarding the embodiments of FIGURES 3 and 4A-B.

FIGURE 7B depicts an embodiment similar to that shown in FIGURE 7A. In the FIGURE 7B embodiment, the power generation device is again positioned in a lateral chamber 24 which is positioned outside of the primary flow passage. More particularly, the power generation device comprises a magnetic coil 150 and a generator armature 152. The generator armature 152 and the magnetic coil 150 form a conventional electrical generator. A generator drive shaft 154 couples the generator armature 152 to a piston body 156 and piston head 158. The drive shaft 154 converts linear motion by the piston body 156 into rotational motion to turn the generator armature. Piston head 158 sealingly engages the wall of the lateral chamber through a seal 162. A spring 160 is sandwiched between the bottom of the piston head 158 and a base 164. It will be appreciated that when a force urges the piston head 158 downwardly, the piston body 156 causes the shaft 154 to turn the generator armature 152. The generator produces electricity that is supplied to electronics and battery package 114 of the type described above. The spring 160 will be compressed such that when the force on the piston head 158 is removed, spring 160 will urge upwardly to place piston head 158 into its normal position.

During operation, assuming that production fluid or other fluid is present within the primary passage 16, pressure waves indicated by the lines 115 are directed downwardly from some position downstream of side passageway 24 and impinge upon the piston head 158. The pressure waves are delivered over a selected intermittent and timed sequence such that piston head 158 will be sequentially urged downwardly when impinged by a pressure wave. During the time period that the pressure wave has passed and before the next pressure wave impinges upon piston head 158, spring 160 will urge piston head 158 upwardly to its normal position. As a result, piston head 158 will undergo a reciprocating upward and downward motion whereby the piston body 156 will similarly reciprocate causing the drive shaft 154 to turn the generator armature 152. The drive shaft 154 may be spiral cut in both directions so that downhole and uphole motion by the piston body 156 drives the generator armature 152 in the same

-18-

direction. The electricity produced by the generator is supplied to the appropriate electronics and storage battery 114 as discussed above regarding the embodiments of FIGURES 3 and 4A-B.

FIGURE 8 depicts an embodiment which is similar to FIGURE 7A in its use of a reciprocating spring actuated piston which moves a magnet with respect to a stationary coil. The primary difference between the embodiments of FIGURES 7A and 8 is that in the FIGURE 8 embodiment, the pressure waves used to periodically impinge upon surface 110 of piston 102 are delivered by a discrete control line 116 which is positioned in the annulus 10 between the production tubing and the casing. The discrete control line 116 may also be used with the embodiment shown in FIGURE 7B.

The pressure waves 115 shown in FIGURES 7A, 7B and 8 may be generated by injecting an energy pulse into the fluid using an external device at the surface of the well. Alternatively, a device may be positioned within the well to produce the pressure waves 115. FIGURE 7C illustrates a choke assembly shown generally as 170. Fluid flow in tubing 176 is sharply and momentarily stopped by the choke assembly 170. This causes a back pressure wave that will flow the length of the well and provide the pressure pulses 115 shown in FIGURES 7A, 7B and 8. The actuator 172 drives a rod 171 having a head 173 that engages a seat assembly 175. The actuator 172 repeatedly engages and disengages the head 173 and the seat assembly 175 to form a series of pressure pulses 115 shown in FIGURES 7A, 7B and 8.

FIGURE 7D is an alternative mechanism for generating the pressure pulses 115. FIGURE 7D illustrates a valve assembly shown generally at 180. Fluid flow in tubing 186 is stopped momentarily by a valve gate 183. The valve gate 183 is connected to a rod 181 which is driven by actuator 182. The actuator 182 repeatedly inserts and removes the valve gate 183 from the tubing 186 to form a series of pressure pulses 115 shown in FIGURES 7A, 7B and 8. An optional side flow path 184 is also shown in FIGURE 7D. The optional side flow path 184 allows fluid to continue to flow in the

-19-

tubing 186 when the valve gate 183 has sealed the primary path of the tubing 186. Thus, it is not necessary to completely shut off the fluid flow to generate the series of pressure pulses.

While many of the foregoing embodiments utilize downhole electrical energy generating apparatus which are positioned in a lateral or side passageway adjacent the primary fluid passageway of the production tubing, it will be appreciated that downhole electrical energy generating apparatus could also be positioned outside of a lateral passageway. That is, energy generating apparatus could simply be positioned within the annulus between the production tubing and the casing or borehole wall. By placement in the annulus, the electrical energy generating apparatus would still not be blocking the primary flow passage of the production tubing as is prevalent with many prior art devices such as the device disclosed in aforementioned U.S. Patent 3,342,267. Examples of locating the downhole energy generating apparatus in the annulus are shown in the following FIGURES 9-11. In FIGURE 9, a downhole electrical generating apparatus is shown which is substantially similar to that shown in FIGURE 2 with the difference being that no outer housing or lateral passageway shrouds the turbine and therefore the electrical generating apparatus is openly positioned in the annulus and is not surrounded by a lateral passageway. It will be appreciated that the turbine is actuated by fluid flowing from perforation 68 in the formation as indicated by the arrows and/or fluid flowing up the primary passageway 22 through opening 29. A packer is shown at 118 downstream of turbine 32 for sealing off the selected portion of the annulus 10 and causing the fluid flowing past turbines 32, 34 to flow back into the primary passageway 22. While the generator 42, energy storage device 50, and electronics 52 are shown enclosed by an enclosure 120, it will be appreciated that these units could also be exposed within the annulus to the annulus fluids. However, it is preferred that units 42, 50 and 52 are protected by enclosure 120 so as to avoid any damage from fluids and other debris within the annulus.

Referring now to FIGURES 10A-10C, still another embodiment of this invention wherein the electrical generating apparatus is positioned within the annulus is shown. In the embodiment of FIGURE 10A-10C, a turbine 122 is rotatably mounted

-20-

onto the outer surface of tubing 16 using a bearing assembly 124. One or more magnets 126 is mounted to a lower surface 128 of turbine 122. As a result, fluid impinging over turbine 122 will rotate both turbine 122 and magnet 126 about the longitudinal axis of production tubing 16. Disposed upstream and in facing relation to turbine 122 and more particularly magnet 126 is an electrical coil 130 which is rigidly mounted about the outer periphery of tubing 16. Connected to coil 130 are appropriate electronics 132 and rechargeable battery 134 of the type described in connection with
5 aforementioned embodiments of FIGURES 3 and 4A-B. In the embodiment of FIGURE 10A, production fluid travels upwardly through annulus 10 from perforations
10 68 formed in the formation 14. This flowing fluid impinges upon turbine 122 thereby rotating turbine 122 about the longitudinal axis of tubing 16 whereupon the magnet 126 will move relative to the coil 130 which is stationary (i.e. fixed) to tubing 16. As a result, the rotating turbine will generate electricity through the interaction between moving magnet 126 and coil 130. After the fluid has impinged upon turbine 122, the
15 fluid will continue to flow through the annulus 10 and enter the primary passageway 22 of tubing 16 through a series of openings 136 and 138. In addition, the fluid will pass through optional centralizer 140.

FIGURE 10B shows a downhole powered generation assembly which is substantially similar to FIGURE 10A with the difference being that in FIGURE 10B,
20 the production fluid which initially impinges upon turbine 122 flows out of the production tubing 16 through a upstream openings 140. A packer 142 is positioned upstream of openings 140 to seal this portion of the annulus 10. After leaving the primary passageway 140, the fluid impinges upon turbine 122 and then travels upwardly and back into the primary passageway through openings 136, 138 as
25 discussed with regard to FIGURE 10A.

The FIGURE 10C embodiment is again substantially identical to the FIGURES 10A and 10B embodiments with the difference being that the fluid which impinges upon turbine 122 neither flows back into the production tubing 16 (as in FIGURE 10A) nor initially emanates from the production tubing 16 (FIGURE 10B). Instead, the fluid
30 flows from the annulus via an appropriate perforation 68 in the formation, impinges

-21-

turbine 122, and thereafter travels upwardly through the annulus. Of course, the fluid may be directed back into the production tubing 16 at a location downstream. In the embodiments shown in FIGURES 10A-10C, the turbine 122 and magnets 126 are positioned above the electrical coil 130. It is understood that the this relationship may be reversed, that is the turbine 122 and magnets 126 may be placed below the electrical coil 130 with the same result being achieved.

Referring now to FIGURE 11, still another embodiment of this invention wherein the electrical generating apparatus is positioned in the annulus is shown. In the FIGURE 11 embodiment, a piezoelectric power generating unit is shown which is substantially similar to the piezoelectric power generating unit of FIGURE 5. Thus, a stack of piezoelectric elements 90 is positioned on the outer circumference of tubing 16 and is, in turn, connected to an electronics unit 91 and rechargeable battery 98 with electronics unit 91 including the power rectifier 92, voltage regulator 94 and charge/power on switch 96 of FIGURE 6. FIGURE 11 also depicts downhole sensors and/or gauges 140 of the type described in aforementioned U.S. Application S.N. 08/385,992. Sensors 140 communicate with a computer/communications module 142. As with the FIGURE 5 embodiment, production fluid flowing through tubing 16 causes stress and/or vibration against the tubing wall which motion is converted by the piezoelectric elements into electrical charges by the electronics unit 91.

While an important feature of the present invention is that the primary passageway in production tubing 16 remain clear for the passage of tools and such items as coil tubing, it will be appreciated that the flexible bladder embodiments of FIGURES 4A and 4B may be positioned within the primary passageway of tubing 16 and yet still not impede or block said passageway unlike prior art devices such as the turbine shown in Patent 3,342,267. For example, referring to FIGURE 12, the flexible bladder 82 is shown mounted between a pair of lower mounts 144 and upper mounts 146 such that production fluid is allowed to easily pass upwardly through bladder 82 towards the surface. It will be appreciated that while the mounts 144, 146 and bladder 82 do narrow to some extent the primary passageway 22, such narrowing is minimal and still permits the passage of coil tubing or other tooling through the center of

-22-

bladder 82. Of course, as in the FIGURES 4A and 4B embodiments, magnets 84 are positioned on the outside of bladder 82 and coils 86, 88 are positioned on either side of magnet 84 so as to generate electricity through the fluxuations of magnet 84 between coils 86, 88. An optional turbulence enhancer 90 is also provided. The electronics package 92 and rechargeable battery 94 are preferably positioned outside of production tubing 16 within the annulus 10 preferably within an enclosure 148 as shown in FIGURE 12.

The rechargeable battery described in each and every one of the numerous embodiments of this invention represents an important feature of the present invention. In an exemplary embodiment, the battery will have the ability to operate at high temperatures (above 175° C), have a long operating life (as much as five years), be of small size (for example sized or otherwise adapted to fit within an envelope of 1" in diameter), have the ability for continuous discharge for instrumentation in microprocessors (10 milliamperes), have the ability for periodic discharge for communications equipment (15 milliamperes per minute at 2% duty cycle), have the ability for a minimum of 100 recharging cycles from external power sources as a generator, include high energy density and excellent self-discharge characteristics. Preferably, the rechargeable battery comprises a solid lithium-metal polymer electrolyte secondary battery of the type described in the paper entitled "Large Lithium Polymer Battery Development: The Immobile Solvent Concept", M. Gauthier et al, the entire contents of which is incorporated herein by reference. Batteries of this type are also disclosed in U.S. Patent Nos. 4,357,401; 4,578,326 and 4,758,483 all of the contents of which are incorporated herein by reference. It is believed that such lithium polymer battery cells are preferred over other battery technology such as nickel cadmium or lead acid due to the higher energy density, smaller size and better self discharge characteristics of the lithium polymer batteries. Still another rechargeable battery which is believed to be especially useful in the present invention are those rechargeable batteries available from Duracell Inc. of Bethel, Connecticut which incorporate therein an integrated circuit chip for extending and/or optimizing the battery life, providing high energy density, high power and a wide temperature range

-23-

for performance. Such batteries are sold by Duracell Inc. under the tradenames DR15, DR17, DR30, DR35 and DR36.

Based on the foregoing, and as shown, for example, in FIGURES 1-6 and 9-12 it will be appreciated that an important feature of this invention is a long-term power supply to be mounted on hydrocarbon production tubing downhole in a wellbore for providing electrical power to equipment mounted on the production tubing comprising (1) an electrical power generating device powered by fluid flow downhole; (2) a rechargeable battery for storing electrical power from the generating device; and (3) a charging circuit receiving electrical power as generated from the generating device and producing a charging current for delivery of power to the battery wherein the battery is recharged on a periodic basis by the charging circuit and serves as a source of power for the downhole equipment.

Although several of the apparatus for generating power are described as being powered by fluid flowing out of the well, it is also possible to generate power by forcing fluid into the well. The orientation of the power generating apparatus may be reversed to accomodate the reverse fluid flow. This would allow power to be generated during applications such as water flood or gas lift. In addition, the power generating apparatus can be made retrievable by mounting the entire power generating apparatus in a side pocket of the well.

The downhole electrical energy generating apparatus of the present invention provides many features and advantages relative to the prior art. An important feature and advantage is that the present invention provides no obstructions within the production tubing. That is, the present invention generates electricity while simultaneously maintaining production tubing 16 obstruction free such that devices including coil tubing may be delivered through the production tubing without interruption. The ability to provide electrical power generation without obstructing the production tubing constitutes an important feature of this invention and an important advance over the prior art such as the turbo generator of U.S. Patent 3,342,267 wherein the turbines cause an impassible obstruction within the production tubing.

-24-

Still other features and advantages of the present invention is the ability to generate electricity using relatively economical and environmentally friendly components. The use of a rechargeable battery allows the present invention to provide electricity both during times when production fluids are flowing as well as those times
5 when production fluid flow has ceased.

It will be appreciated that in those embodiments which utilize a movable magnet and fixed coil, an acceptable (although less preferred) arrangement is where the magnet is fixed and the coil is movable.

It will further be appreciated that in those embodiments of this invention where
10 fluid motion gives rise to power generation, the fluid may originate either from one or both of the production tubing or the annulus.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present
15 invention has been described by way of illustrations and not limitation.

What is claimed is:

-25-

CLAIM 1. An electrical energy generating apparatus for generating electricity downhole in a well, comprising:

a primary flow passageway and side passageway laterally displaced from said primary passageway; and

5 an electrical generating device positioned, at least in part, in said side passageway, said electrical generating device adapted to generate electricity in response to fluid flowing through said side passageway.

CLAIM 2. The apparatus of claim 1 wherein:

said primary flow passageway and said side passageway are housed in a housing.

CLAIM 3. The apparatus of claim 1 wherein:

said side passageway communicates with said primary passageway to allow fluid from said primary passageway to flow into said side passageway.

CLAIM 4. The apparatus of claim 3 wherein:

said side passageway communicates with said primary passageway through at least one opening between said primary and side passageways.

CLAIM 5. The apparatus of claim 1 wherein said primary flow passageway and said side passageway are adapted for positioning in a borehole such that an annulus is defined between an inner wall of the borehole and the side passageway and wherein:

5 said side passageway communicates with said annulus to allow fluid from said annulus to flow into said side passageway.

CLAIM 6. The apparatus of claim 5 wherein:

said side passageway communicates with said annulus through at least one opening between said side passageway and said annulus.

-26-

CLAIM 7. The apparatus of claim 3, wherein said primary flow passageway and said side passageway are adapted for positioning in a borehole such that an annulus is defined between an inner wall of the borehole and the side passageway and wherein:
said side passageway communicates with said annulus to allow fluid from said
5 annulus to flow into said side passageway.

CLAIM 8. The apparatus of claim 1 wherein said electrical generating device comprises:
at least one turbine operatively connected within said side passageway for
movement in response to fluid flowing through said side passageway; and
5 an electrical generator associated with said side passageway and operatively
connected to said turbine for generating electricity in response to movement by said
turbine.

CLAIM 9. The apparatus of claim 1 wherein said electrical generating device comprises:
a magnetic field extending across said side passageway, said magnetic field
being created in response to fluid flowing through said side passageway; and
5 an electrical energy converter associated with said side passageway for
converting magnetic flux created by said magnetic field into electrical energy.

CLAIM 10. The apparatus of claim 9 wherein said magnetic field comprises:
a magnetic reed located within said side passageway and movable in response
to flowing fluid; and
a coil spaced from and associated with said reed.

-27-

CLAIM 11. The apparatus of claim 9 wherein said magnetic field comprises:

a flexible bladder having an interior and an exterior, said bladder being located within said side passageway, said bladder including an opening for receiving fluid to the interior thereof;

5 at least one magnet on the exterior of said bladder; and

a coil spaced from and associated with said magnet wherein said magnet moves relative to said coil when fluid flows into said bladder.

CLAIM 12. The apparatus of claim 11 including:

a turbulence enhancer upstream of said bladder.

CLAIM 13. The apparatus of claim 1 wherein said electrical generating device comprises:

a piezoelectric device positioned within said side passageway and being responsive to movement caused by flowing fluid; and

5 a converter for converting said signals from said piezoelectric device to electrical energy.

CLAIM 14. The apparatus of claim 1 including:

a flow diverter in said housing for diverting fluid from said primary flow passageway to said side passageway.

CLAIM 15. The apparatus of claim 1 including:

a rechargeable battery in said side passageway, said electrical generating device being operatively connected to said battery for charging said battery.

CLAIM 16. The apparatus of claim 15 wherein said battery comprises:

at least one polymer lithium power cell.

-28-

CLAIM 17. The apparatus of claim 15 wherein said battery comprises:
at least one battery which includes an integrated circuit for optimizing battery life.

CLAIM 18. The apparatus of claim 1 wherein:
at least a portion of said electrical generating device is enclosed by a fluid tight enclosure.

CLAIM 19. The apparatus of claim 1 including:
an electrical device operatively connected to said electrical generating device wherein said electrical generating device provides electrical power to said electrical device.

CLAIM 20. The apparatus of claim 19 wherein:
said electrical device comprises a computer.

CLAIM 21. The apparatus of claim 15 including:
an electrical device operatively connected to said battery wherein said battery provides electrical power to said electrical device.

CLAIM 22. The apparatus of claim 21 wherein:
said electrical device is selectively connected to either said battery or said electrical generating device.

-29-

CLAIM 23. A production well comprising:

a first section of production tubing;

a second section of production tubing; and

a downhole electrical energy generating apparatus positioned between and
operatively connected to said first and second sections of production tubing, said
electrical energy generating apparatus including;

(a) a primary flow passageway and a side passageway laterally displaced
from said primary passageway; and

(b) an electrical generating device positioned at least in part in said side
passageway, said electrical generating device adapted to generate electricity in
response to fluid flowing through said side passageway.

CLAIM 24. An electrical energy generating apparatus for generating electricity
downhole in a well, comprising:

a movable magnetic field extending across a selected area downhole, said
movable magnetic field being created in response to the flow of fluid; and

an electrical energy converter for converting magnetic flux created by said
movable magnetic field into electrical energy.

CLAIM 25. The apparatus of claim 24 wherein said movable magnetic field
comprises:

a magnetic reed located within said side passageway and movable in response
to flowing fluid; and

a coil spaced from and associated with said reed.

-30-

CLAIM 26. The apparatus of claim 24 wherein said movable magnetic field comprises:

a flexible bladder having an interior and an exterior, said bladder being located within said side passageway, said bladder including an opening for receiving fluid to the interior thereof;

5

at least one magnet on the exterior of said bladder; and

a coil spaced from and associated with said magnet wherein said magnet moves relative to said coil when fluid flows into said bladder.

CLAIM 27. The apparatus of claim 26 including:

a turbulence enhancer upstream of said bladder.

CLAIM 28. The apparatus of claim 26 including production tubing in said well for housing the flowing fluid and wherein:

said flexible bladder is positioned within said production tubing and is axially aligned with said production tubing.

CLAIM 29. An electrical generating apparatus for generating electricity downhole in a well, comprising:

a movable magnetic field extending across a selected area downhole, said magnetic field being created in response to pressure pulses traveling through a fluid pathway; and

5

an electrical energy converter for converting magnetic flux created by said movable magnetic field into electrical energy.

-31-

CLAIM 30. The apparatus of claim 29 wherein said electrical generating apparatus comprises:

a spring actuated magnet; and

5 a coil spaced from and magnetically communicating with said spring actuated magnet wherein said pressure pulses cause said spring actuated magnet to move relative to said coil.

CLAIM 31. The apparatus of claim 29 including tubing in said well for housing fluid and wherein said pressure pulses travel through said tubing.

CLAIM 32. The apparatus of claim 30 including tubing in said well for housing fluid and wherein said pressure pulses travel through said tubing.

CLAIM 33. The apparatus of claim 32 wherein:
said spring actuated magnet and coil are laterally offset from said tubing.

CLAIM 34. The apparatus of claim 29 including tubing in said well for housing fluid and wherein:
said pressure pulses travel through a conduit having fluid therein which is laterally offset from said tubing.

CLAIM 35. An electrical generating apparatus for generating electricity downhole in a well, comprising:

a piston positioned in a selected area downhole, said piston being moved in a first direction in response to pressure pulses traveling through a fluid pathway; and

5 an electrical energy generator coupled to said piston for generating electrical energy in response to motion by said piston.

-32-

CLAIM 36. The apparatus of claim 35 further comprising:

a spring connected to said piston, said spring moving said piston in a second direction opposite to said first direction.

CLAIM 37. The apparatus of claim 36 wherein said electrical energy generator comprises:

a magnetic coil; and

5 a generator armature which rotates within said magnetic coil to generate said electrical energy.

CLAIM 38. The apparatus of claim 37 further comprising a drive shaft connected to said piston and said generator armature, said drive shaft rotating said generator armature when said piston moves in said first direction and said second direction.

CLAIM 39. The apparatus of claim 35 including tubing in said well for housing fluid and wherein:

said pressure pulses travel through a conduit having fluid therein which is laterally offset from said tubing.

CLAIM 40. An electrical energy generating apparatus for generating electricity downhole in a well, comprising:

a primary flow passageway having an interior and an exterior; and

5 an electrical generating device positioned on said exterior of said primary flow passageway, said electrical generating device adapted to generate electricity in response to fluid flowing along said exterior of said primary passageway.

-33-

CLAIM 41. The apparatus of claim 40 wherein said electrical generating device comprises:

at least one turbine being operative in response to said flowing fluid; and
an electrical generator operatively connected to said turbine for generating
5 electricity in response to movement by said turbine.

CLAIM 42. The apparatus of claim 40 wherein said electrical generating apparatus comprises:

a rotating member for rotating about the exterior of said primary flow
passageway in alignment with the longitudinal axis of said primary flow passageway;
5 at least one magnet mounted on said rotating member and being rotatable with
said rotating member; and

a coil positioned about the exterior of the primary flow passageway, said coil
being spaced from and associated with said magnet wherein said magnet moves relative
to said coil when fluid flows through said turbine.

CLAIM 43. The apparatus of claim 42 wherein said primary flow passageway
comprises tubing and the exterior of said primary flow passageway comprises an
annulus and wherein:

said fluid flows through said turbine and is directed into said tubing
5 downstream of said turbine.

CLAIM 44. The apparatus of claim 43 wherein:

said fluid is directed from the interior of said tubing to said annulus upstream of
said turbine.

-34-

CLAIM 45. An electrical generating apparatus for generating electricity downhole in a well, comprising:

a primary flow passageway and a side passageway laterally displaced from said primary flow passageway; and

5 an electrical generating device positioned in said side passageway, said electrical generating device adapted to generate electricity in response to fluid flowing downhole in the well.

CLAIM 46. A production well comprising:

a section of production tubing having an interior flow passage and an exterior;

a piezoelectric device positioned on said exterior of said tubing and being responsive to movement caused by flowing fluid; and

5 a converter for converting signals from said piezoelectric device to electrical energy.

CLAIM 47. The well of claim 46 wherein said converter includes:

a power rectifier operatively connected to said piezoelectric device;

a voltage regulator for receiving rectified signals from said power rectifier;

at least one rechargeable battery; and

5 a switch operatively connected between said voltage regulator and said battery.

CLAIM 48. A production well comprising:

a section of production tubing;

a downhole power generator associated with said production tubing; and

at least one rechargeable battery operatively connected to said power generator.

CLAIM 49. The well of claim 48 wherein:

said battery comprises a lithium polymer battery.

-35-

CLAIM 50. The well of claim 49 wherein:

said battery includes an integrated circuit for optimizing performance.

CLAIM 51. The well of claim 48 including:

at least two rechargeable batteries wherein a first of said batteries is recharged while a second of said batteries is being used to provide power to a device.

CLAIM 52. A long-term power supply to be mounted on hydrocarbon production tubing downhole in a wellbore for providing electrical power to equipment mounted on the production tubing comprising:

an electrical power generating device powered by fluid flow downhole;

5 a rechargeable battery for storing electrical power from the generating device;
and

a charging circuit receiving electrical power as generated from the generating device and producing a charging current for delivery of power to the battery;

wherein the battery is recharged on a periodic basis by the charging circuit and
10 serves as a source of power for the downhole equipment.

CLAIM 53. The well of claim 52 wherein:

said battery comprises a lithium polymer battery.

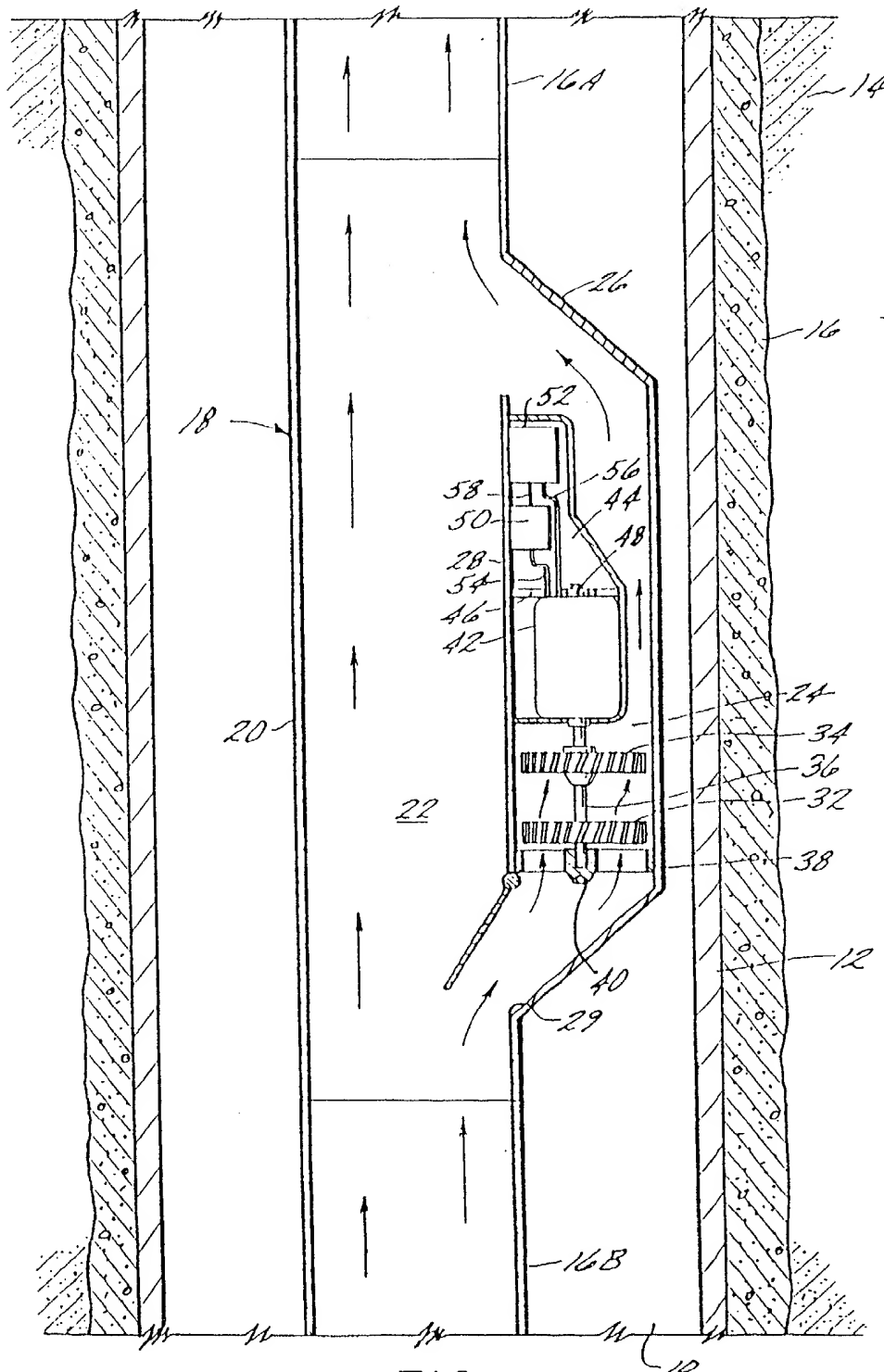
CLAIM 54. The well of claim 53 wherein:

said battery includes an integrated circuit for optimizing performance.

CLAIM 55. The well of claim 52 including:

at least two rechargeable batteries wherein a first of said batteries is recharged while a second of said batteries is being used to provide power to a device.

1/18



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2/18

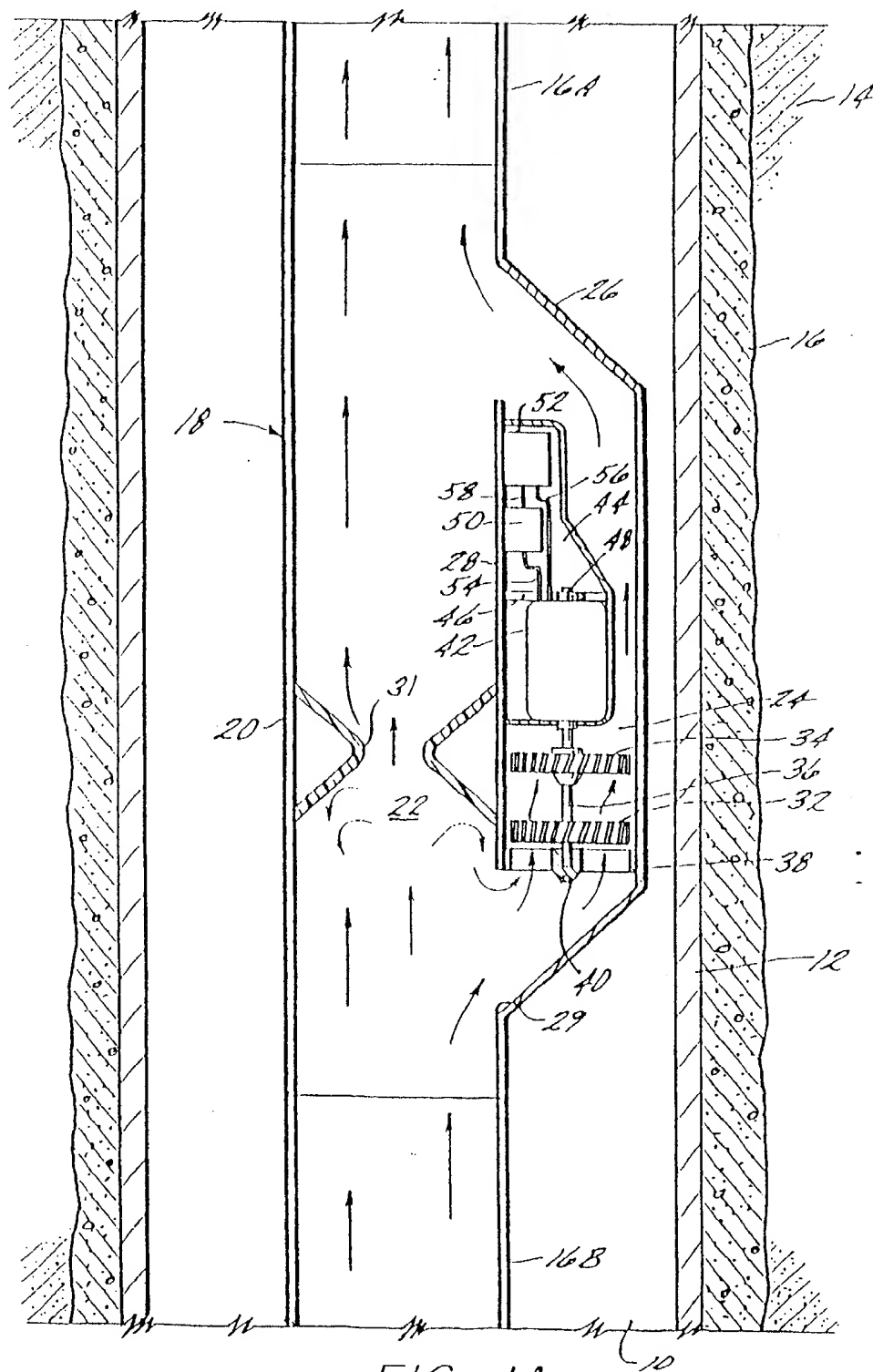
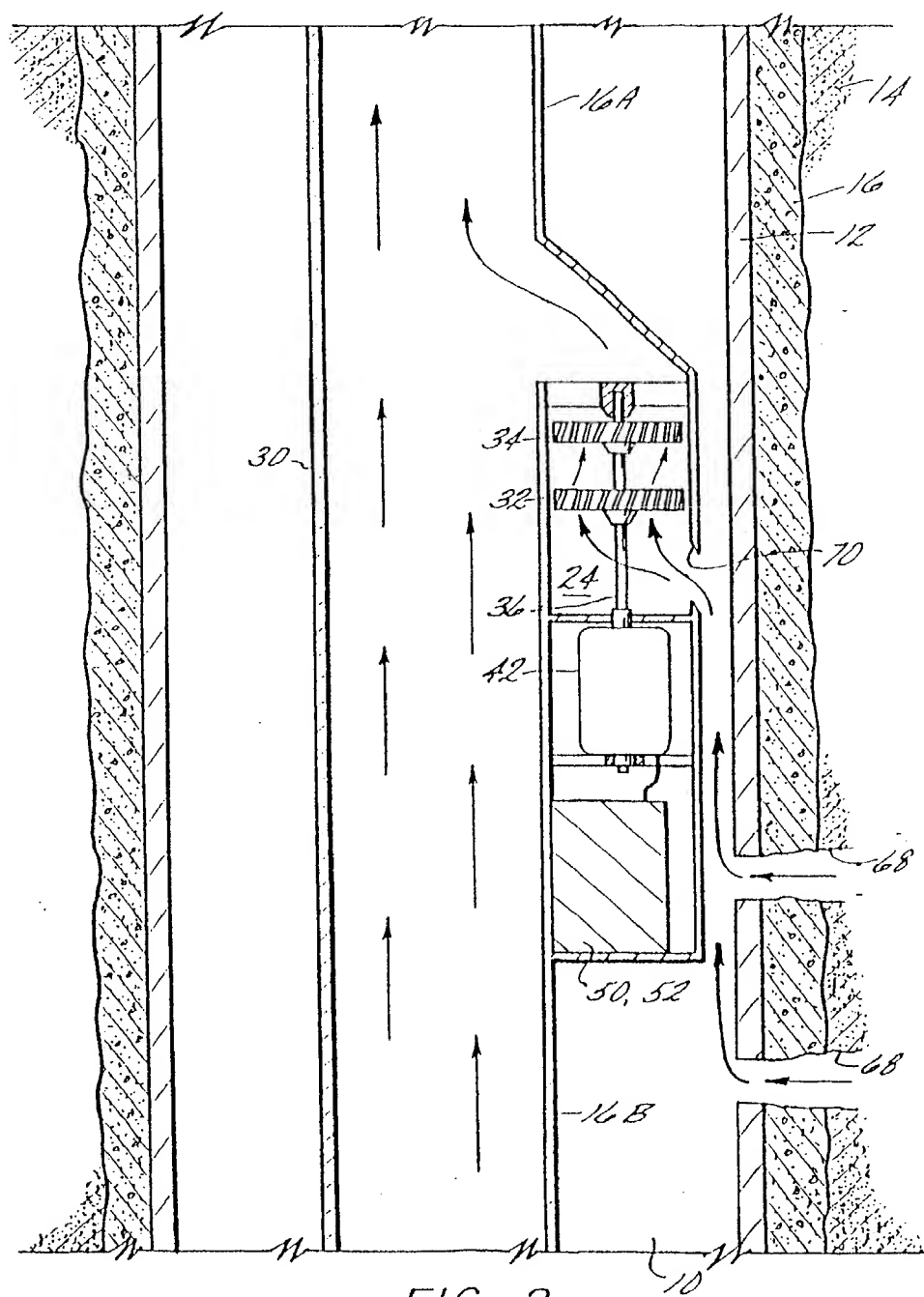


FIG. 1A

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3/18



4/18

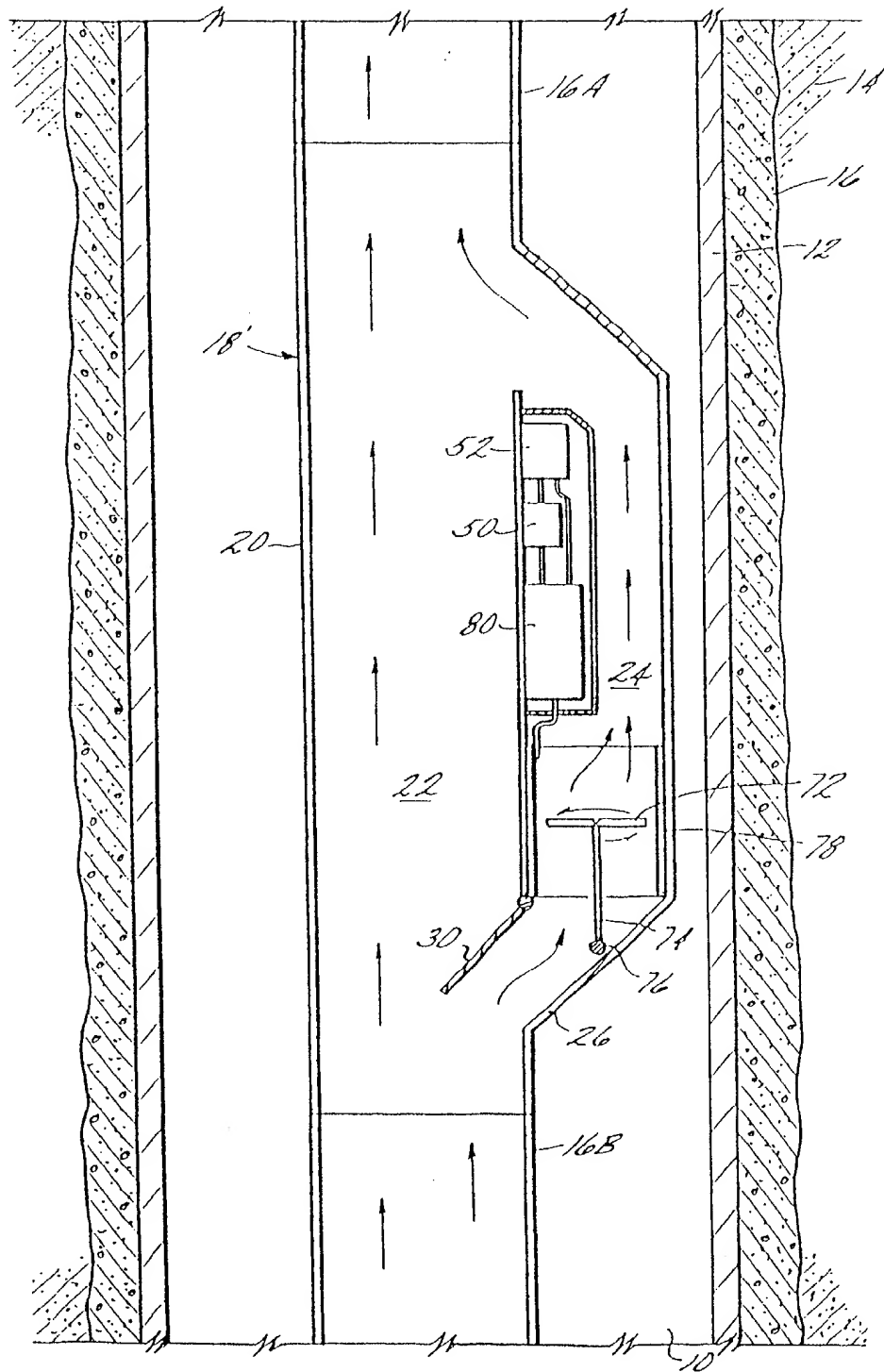
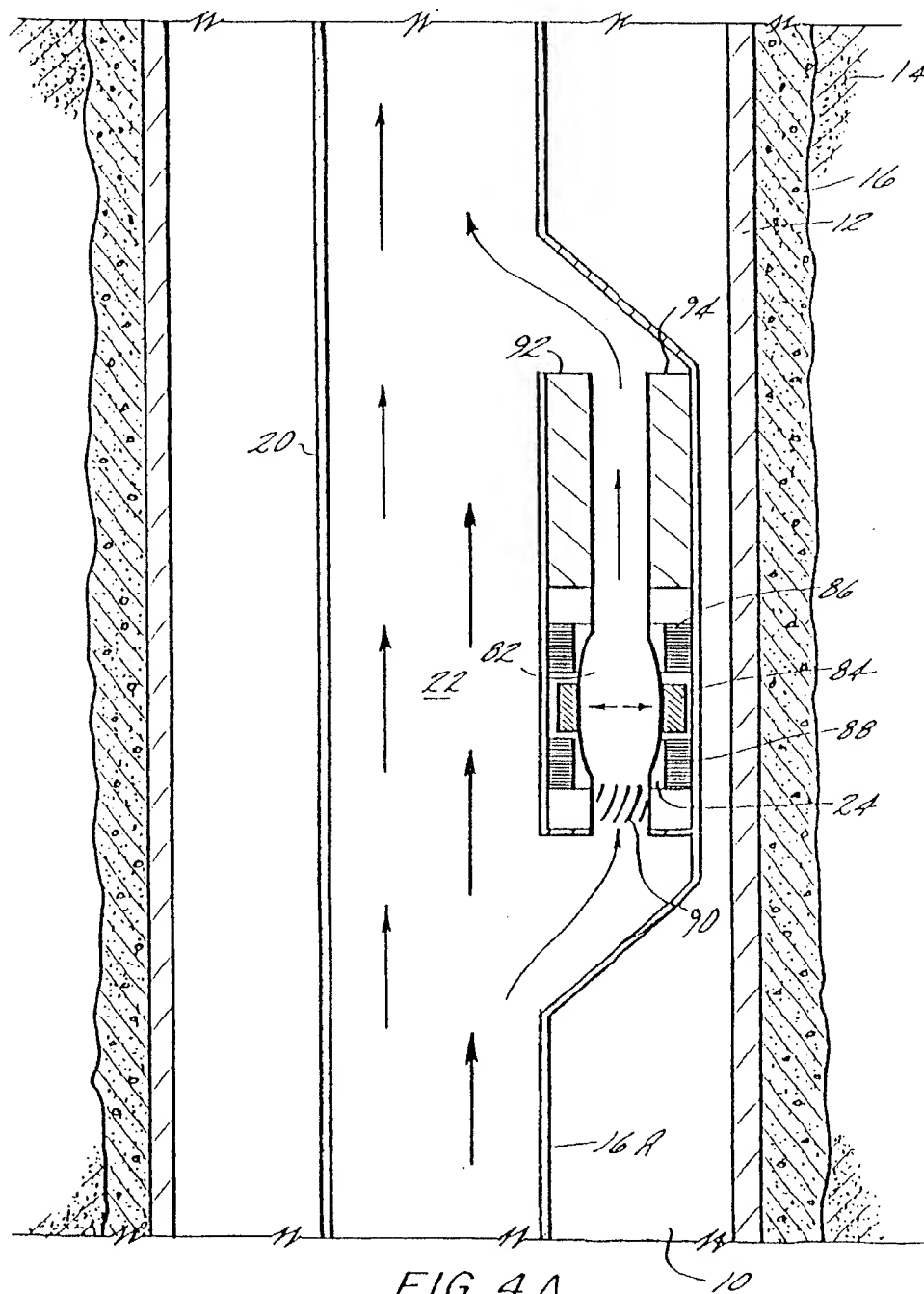


FIG. 3

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5/18



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6/18

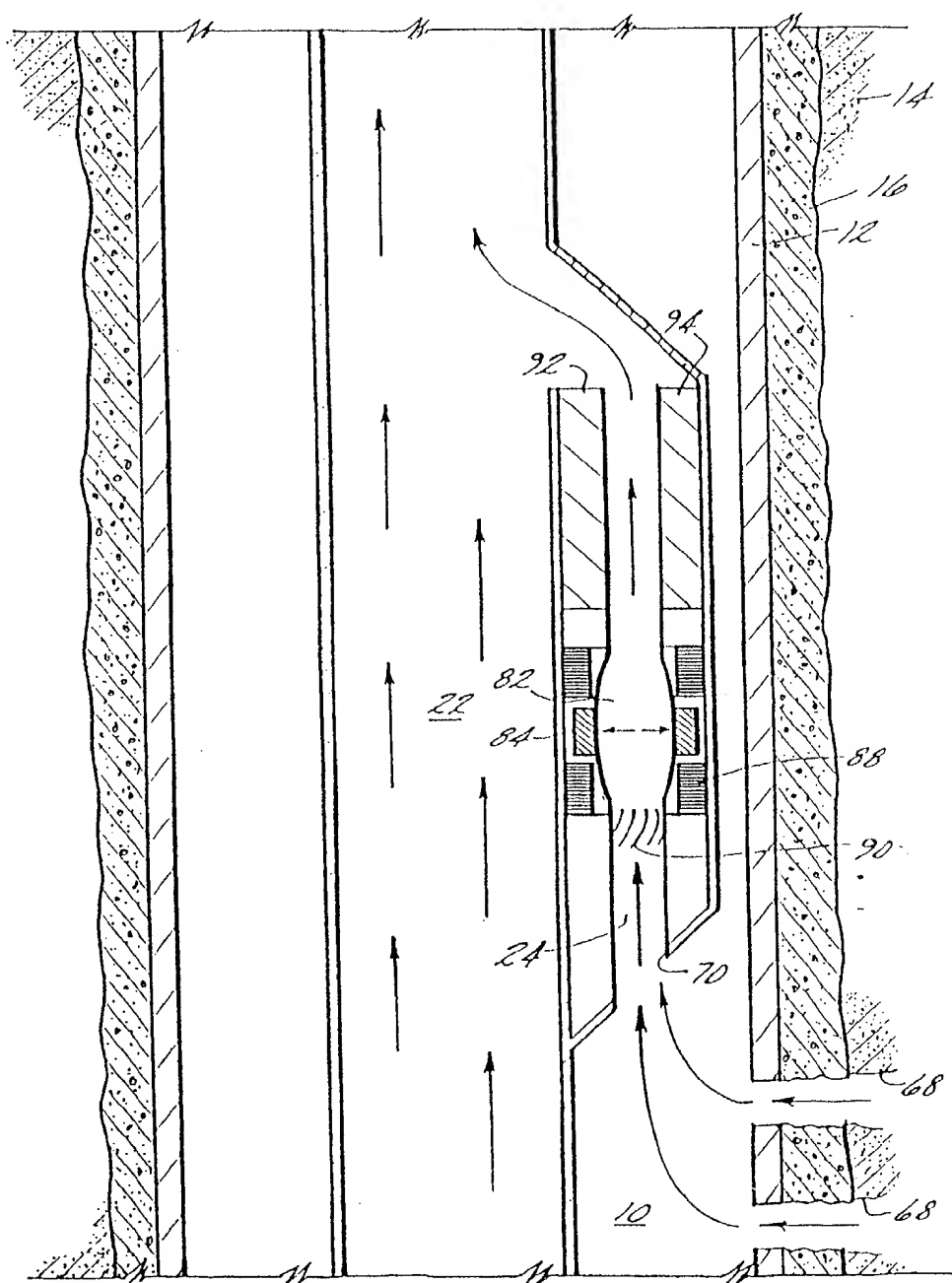


FIG. 4B

7/18

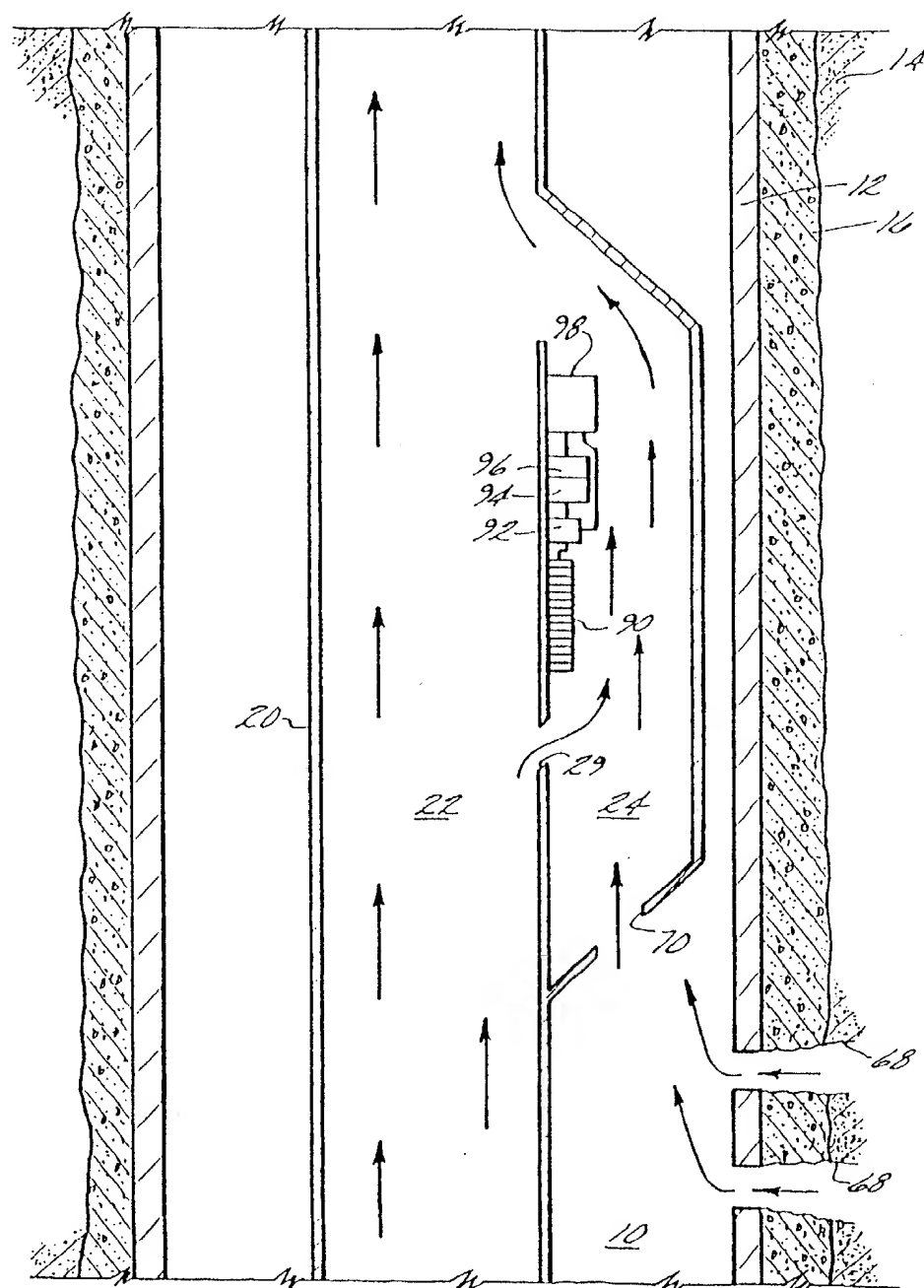


FIG. 5

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8/18

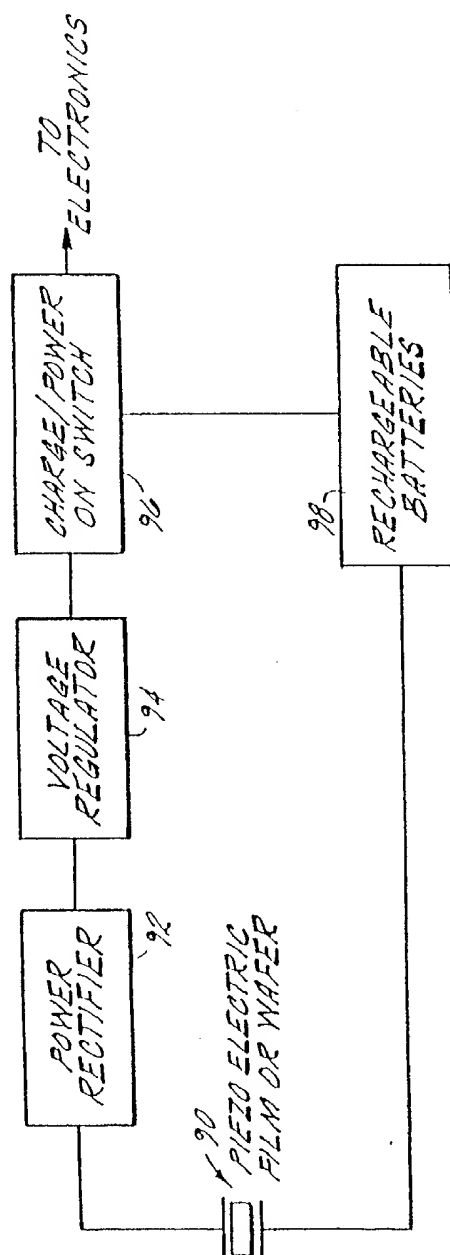


FIG. 6

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9/18

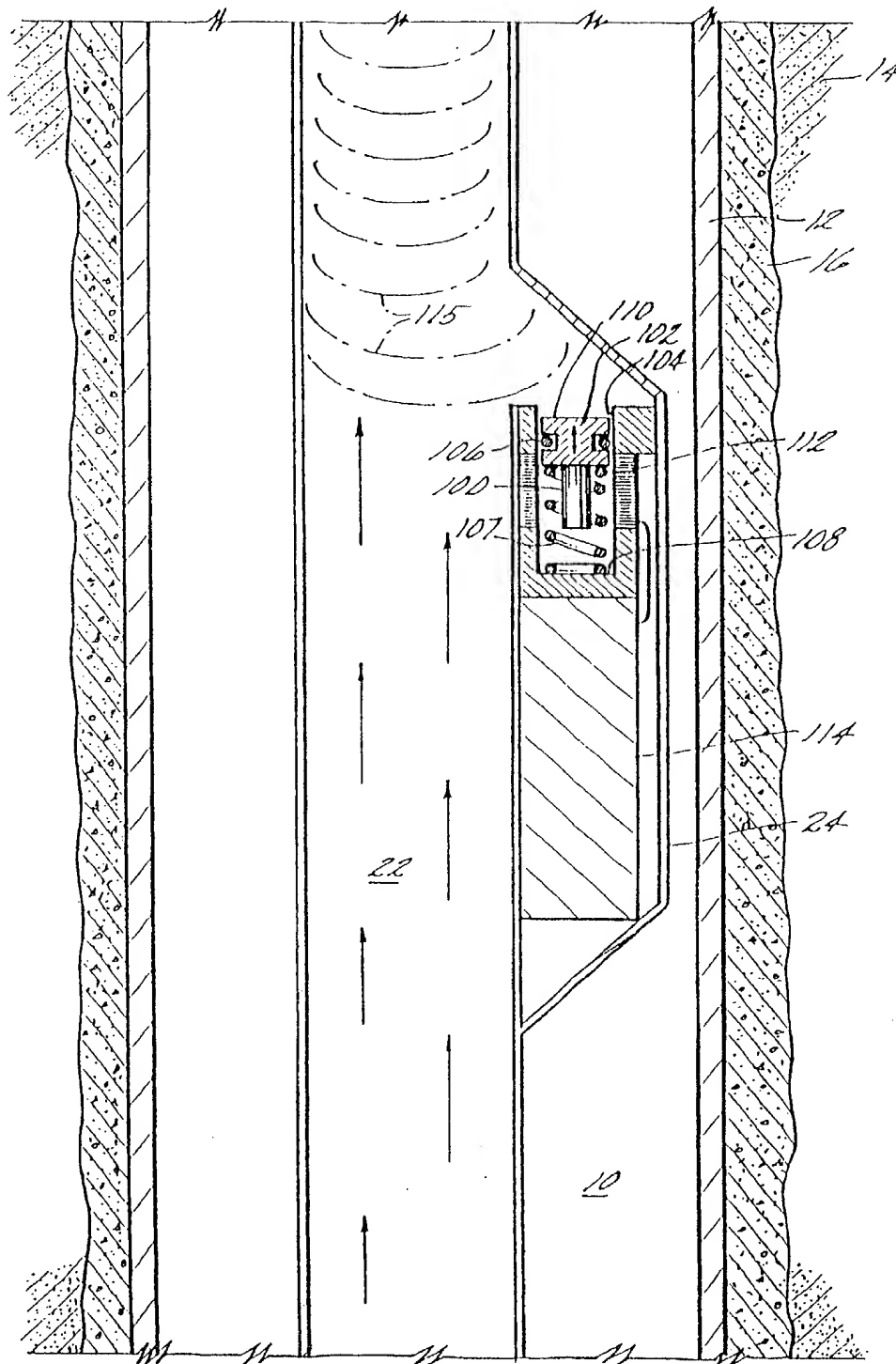


FIG. 7A

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10/18

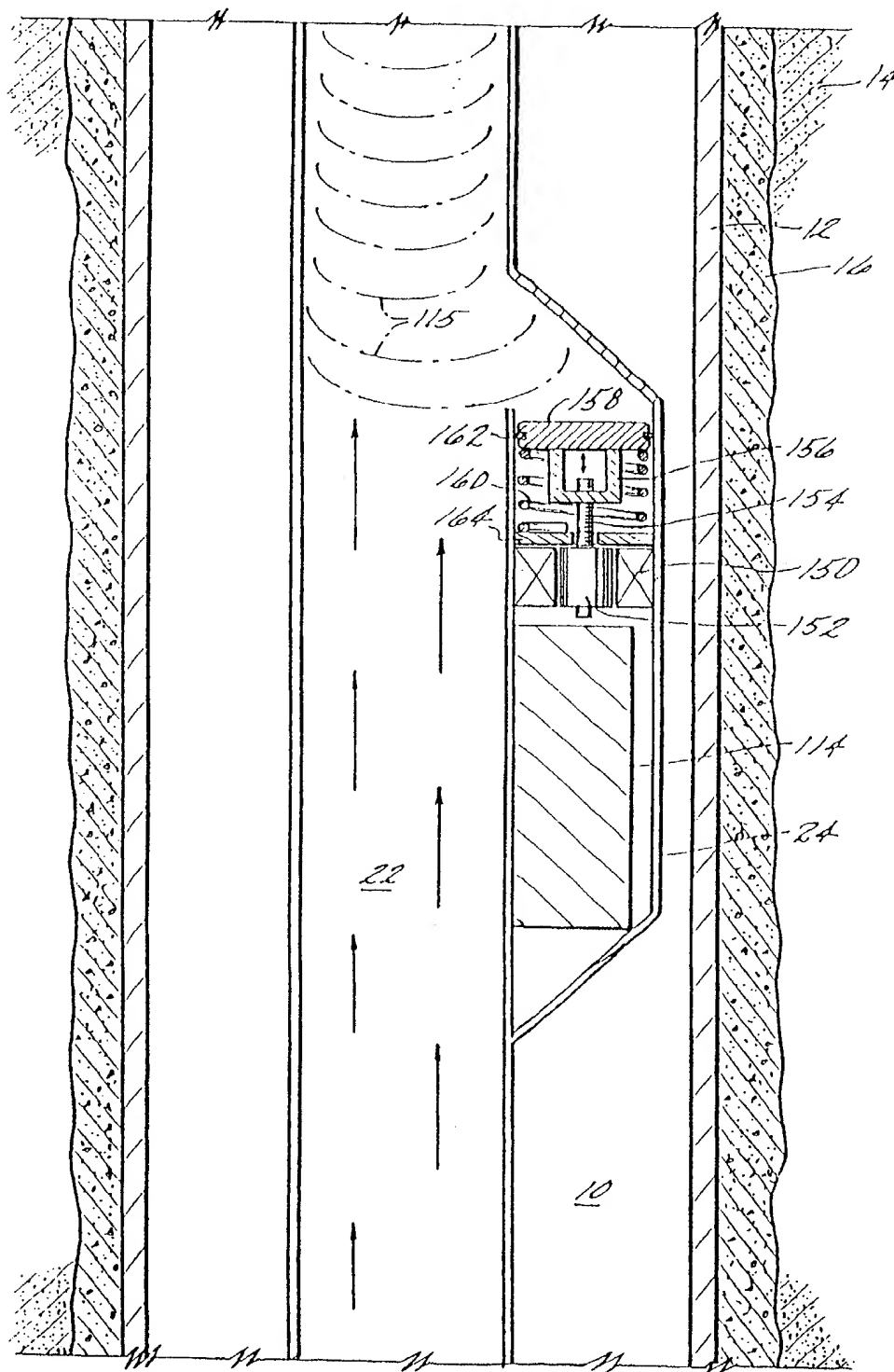


FIG. 7B

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11/18

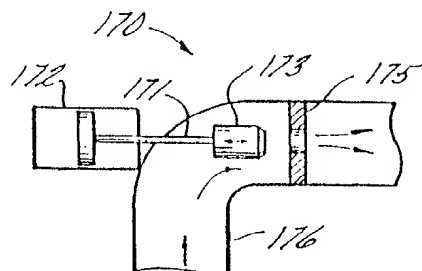


FIG. 7C

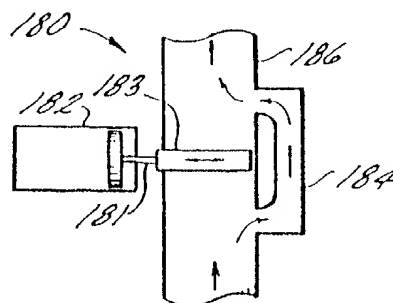


FIG. 7D

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12/18

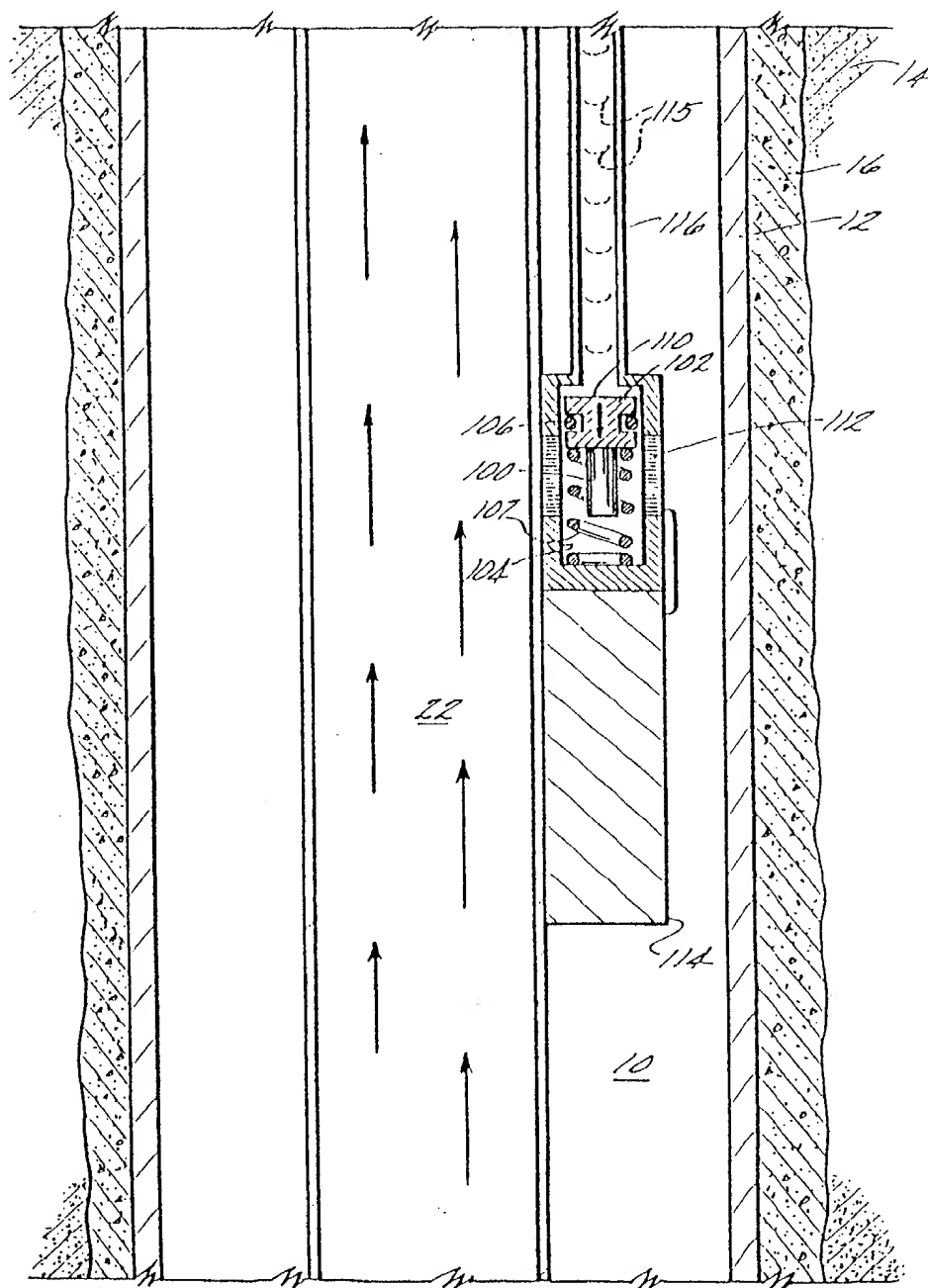
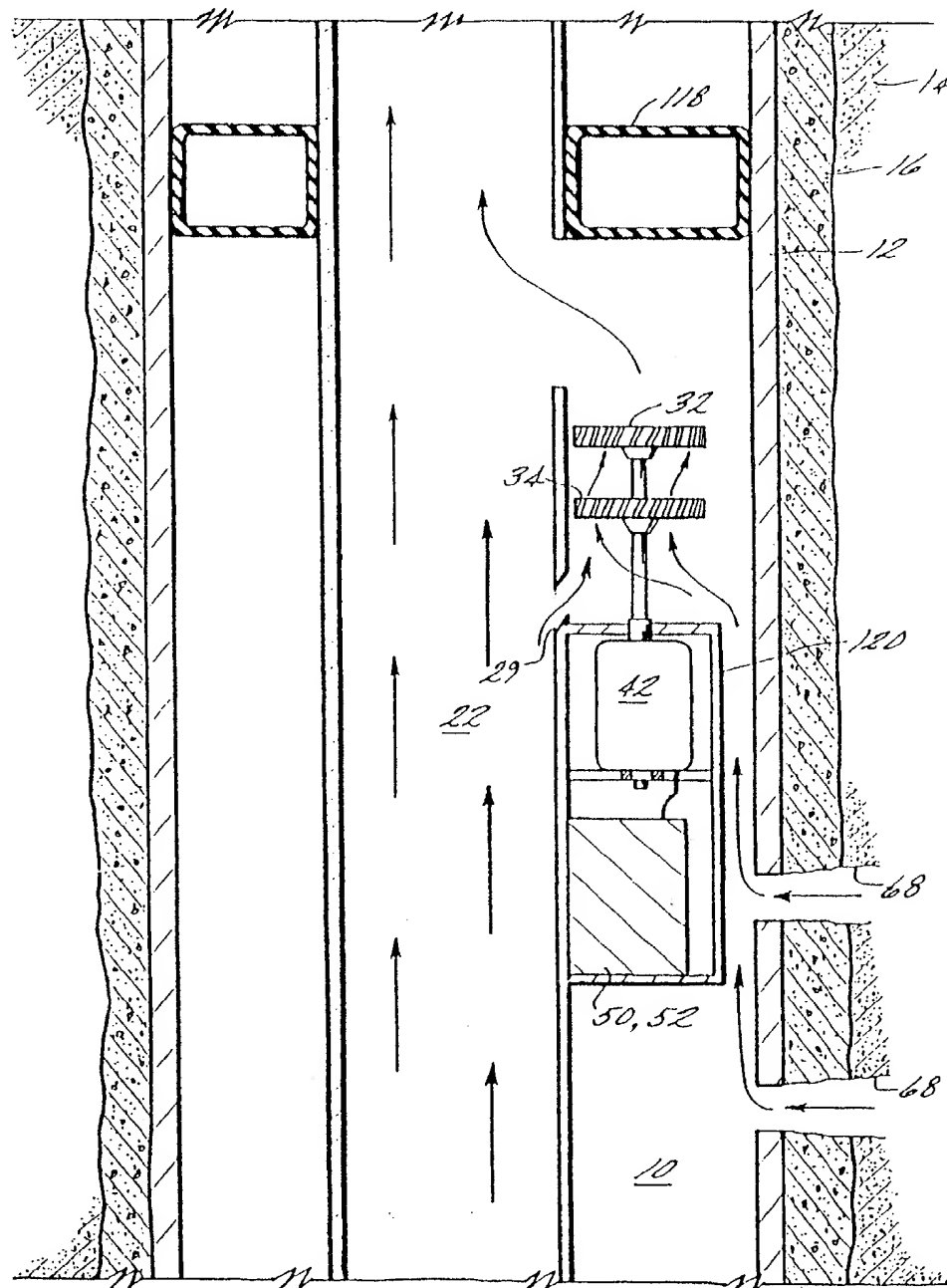


FIG. 8



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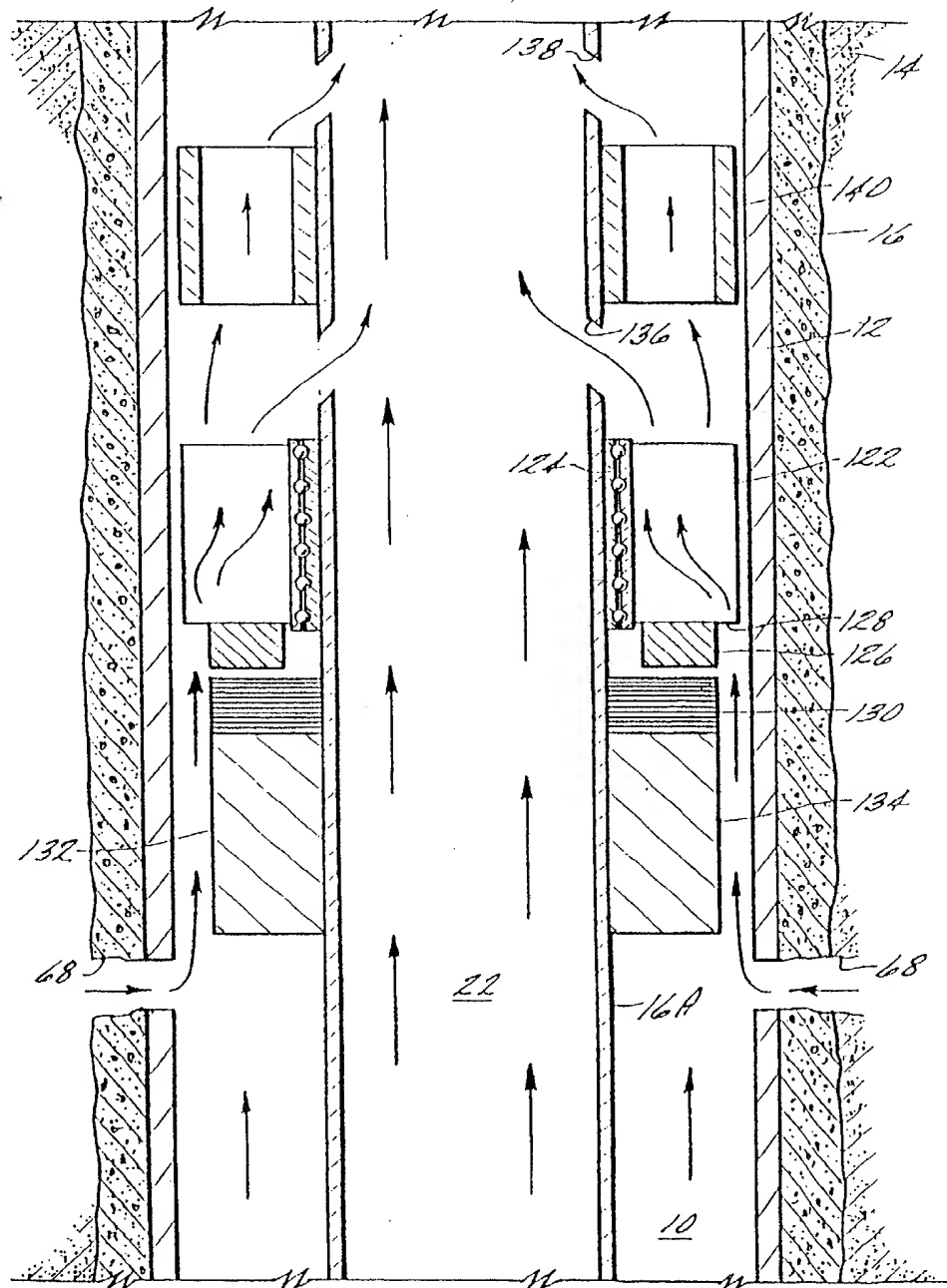


FIG. 10A

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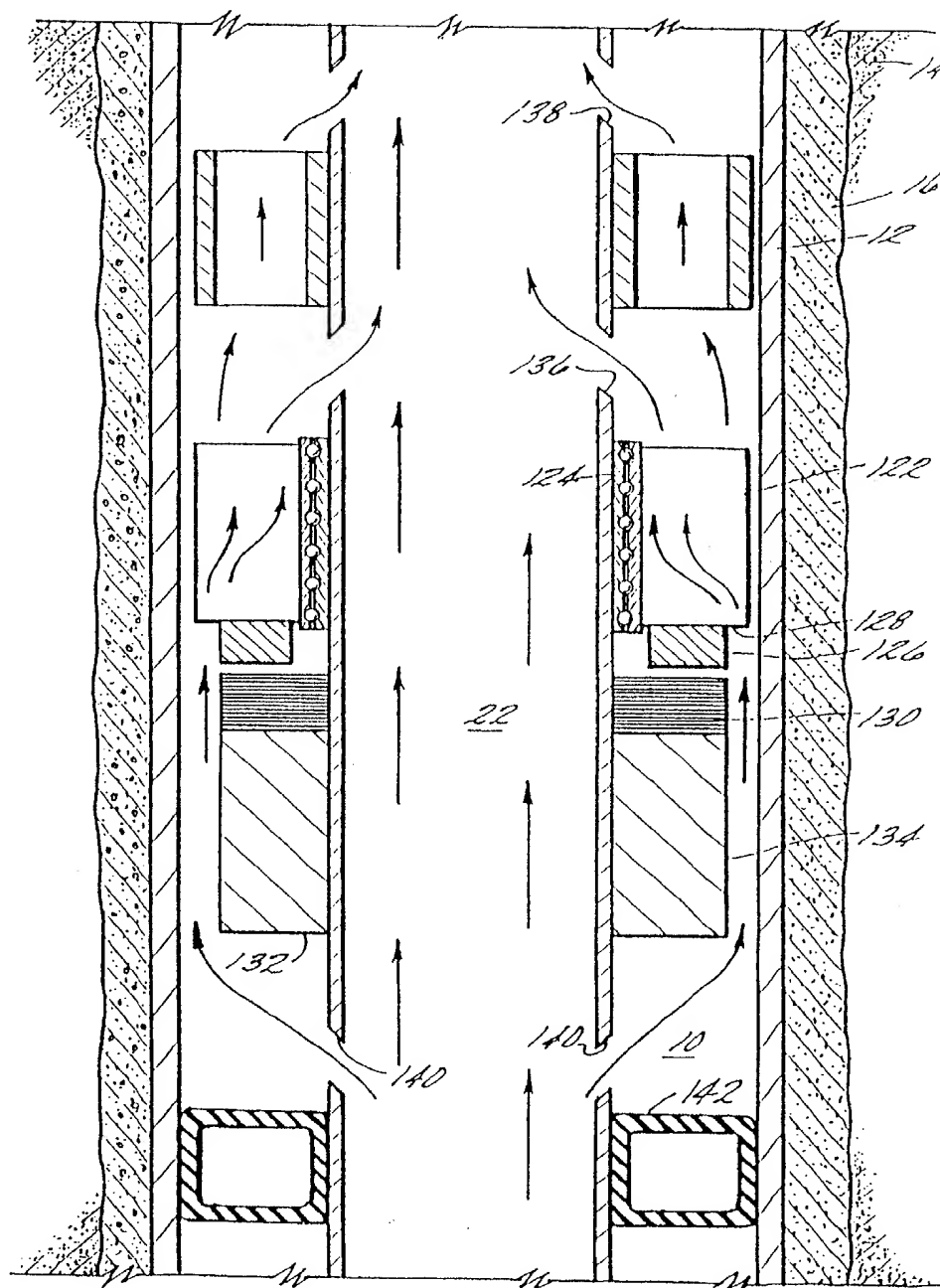
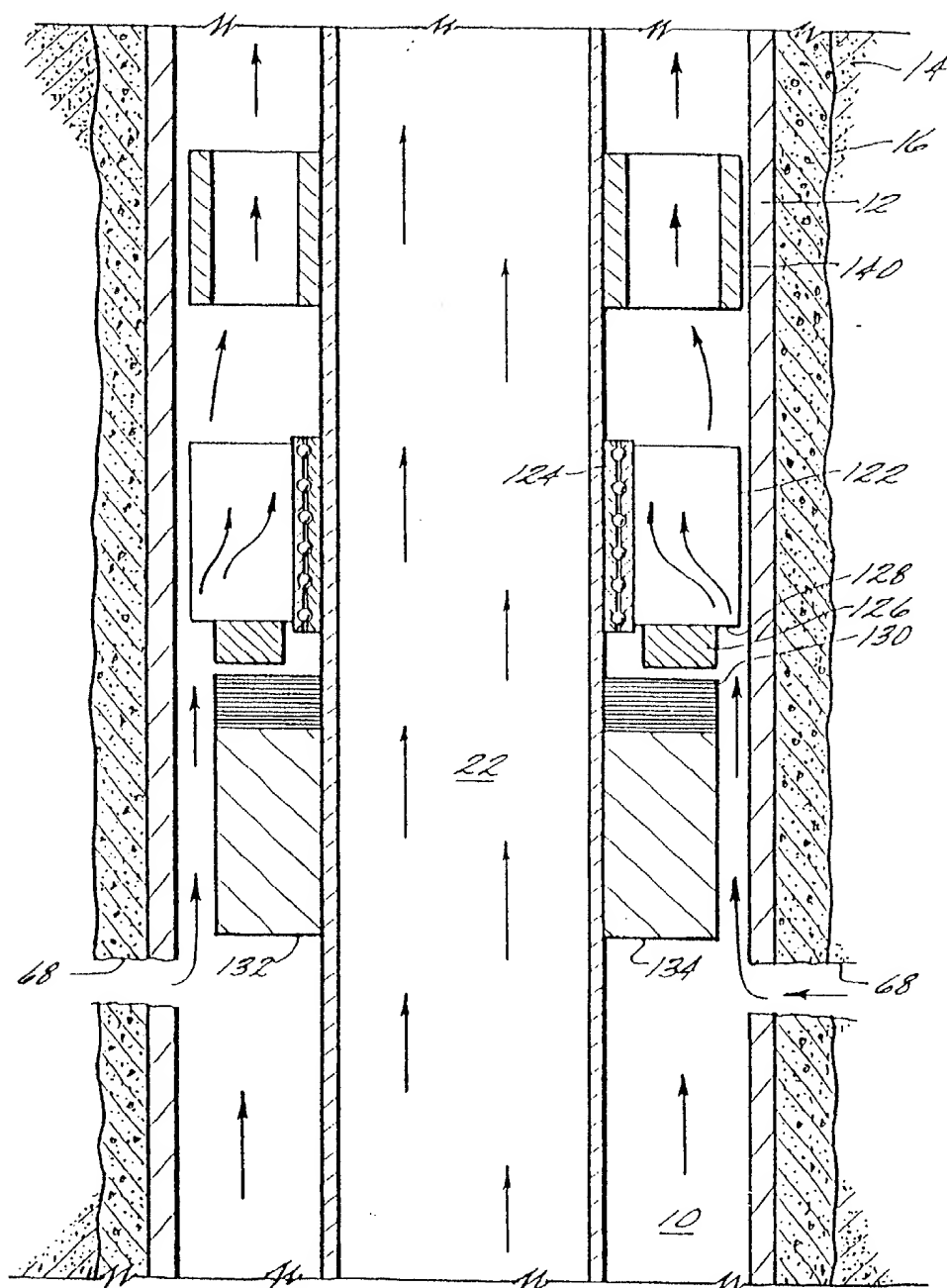


FIG. 10B

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FIG. 10C**SUBSTITUTE SHEET (RULE 26)**

17/18

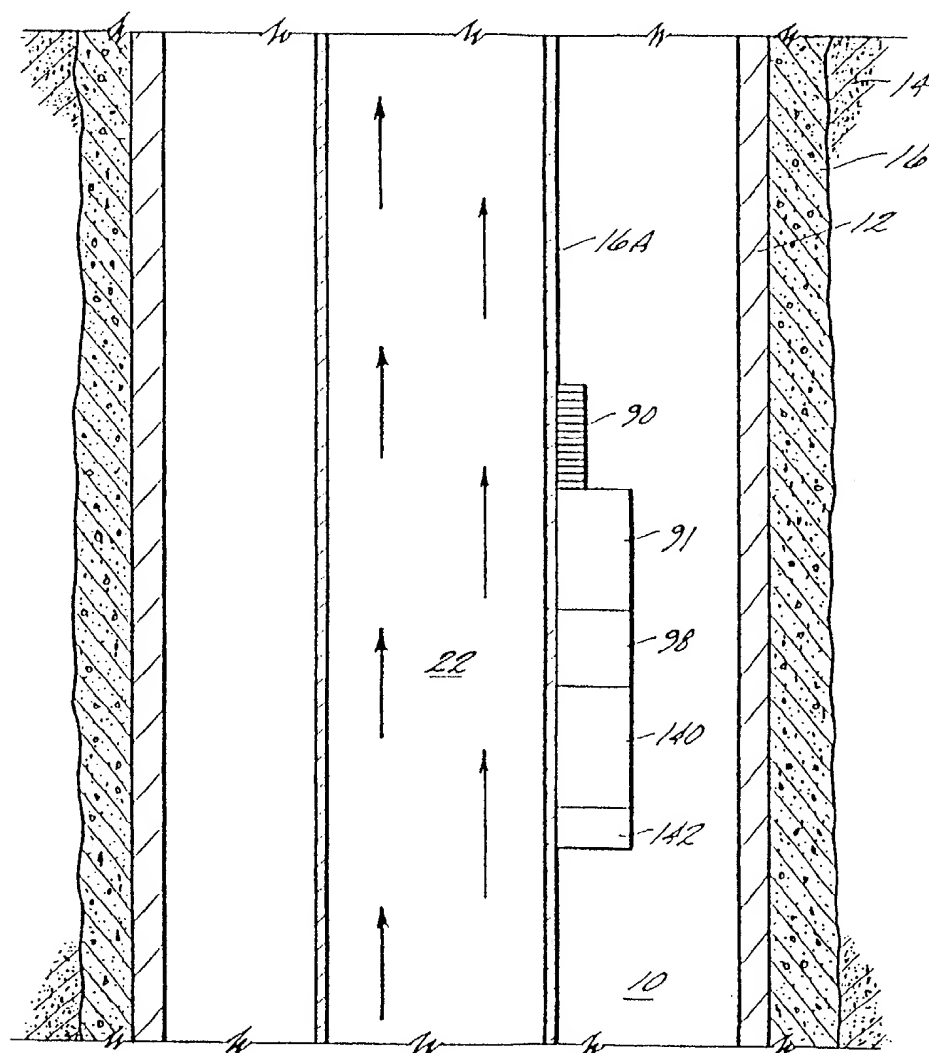


FIG. 11

18/18

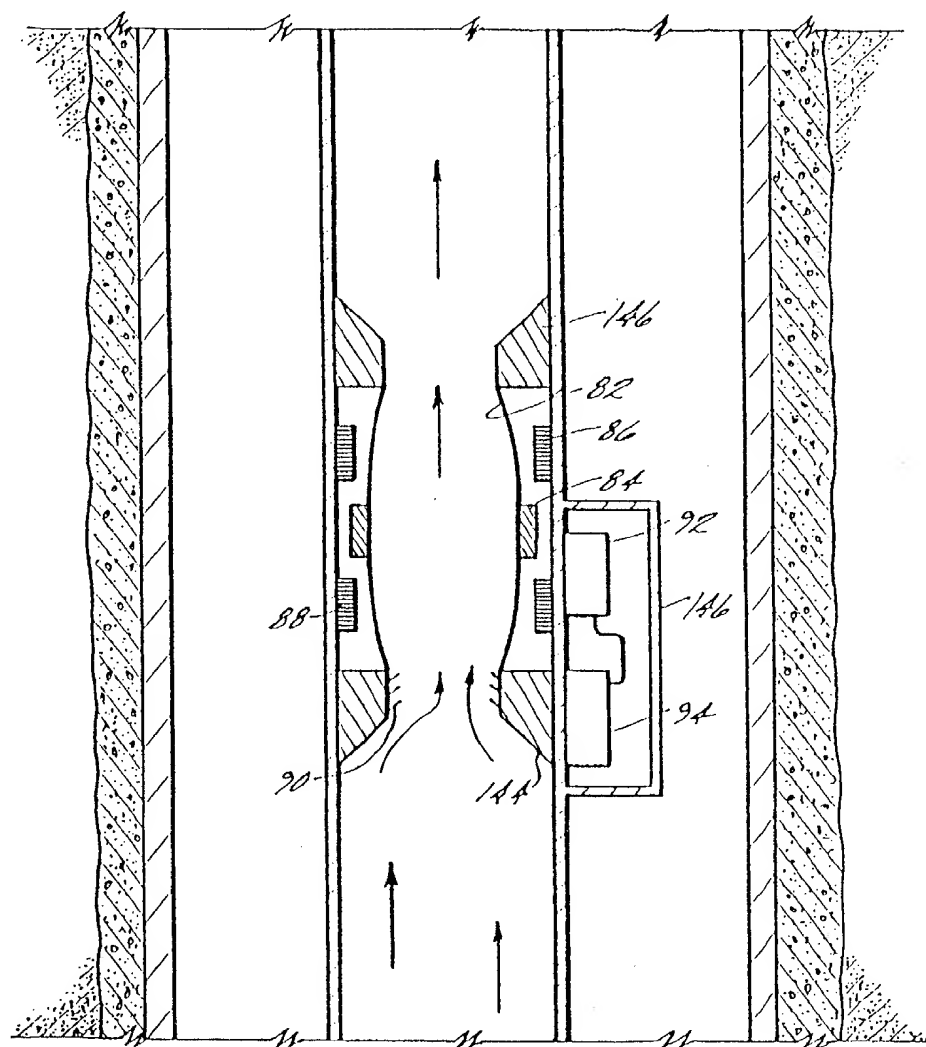


FIG. 12

1/18

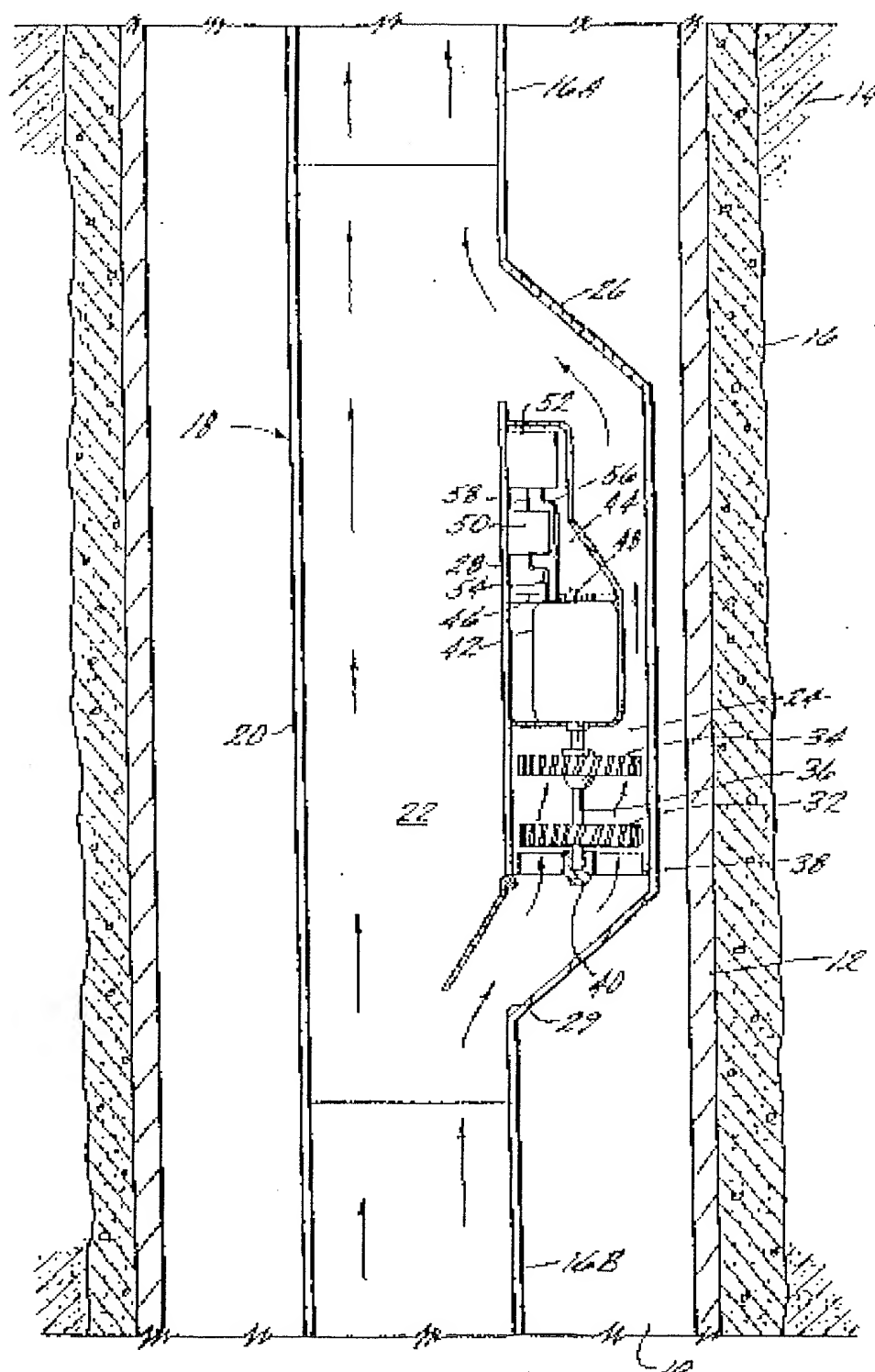
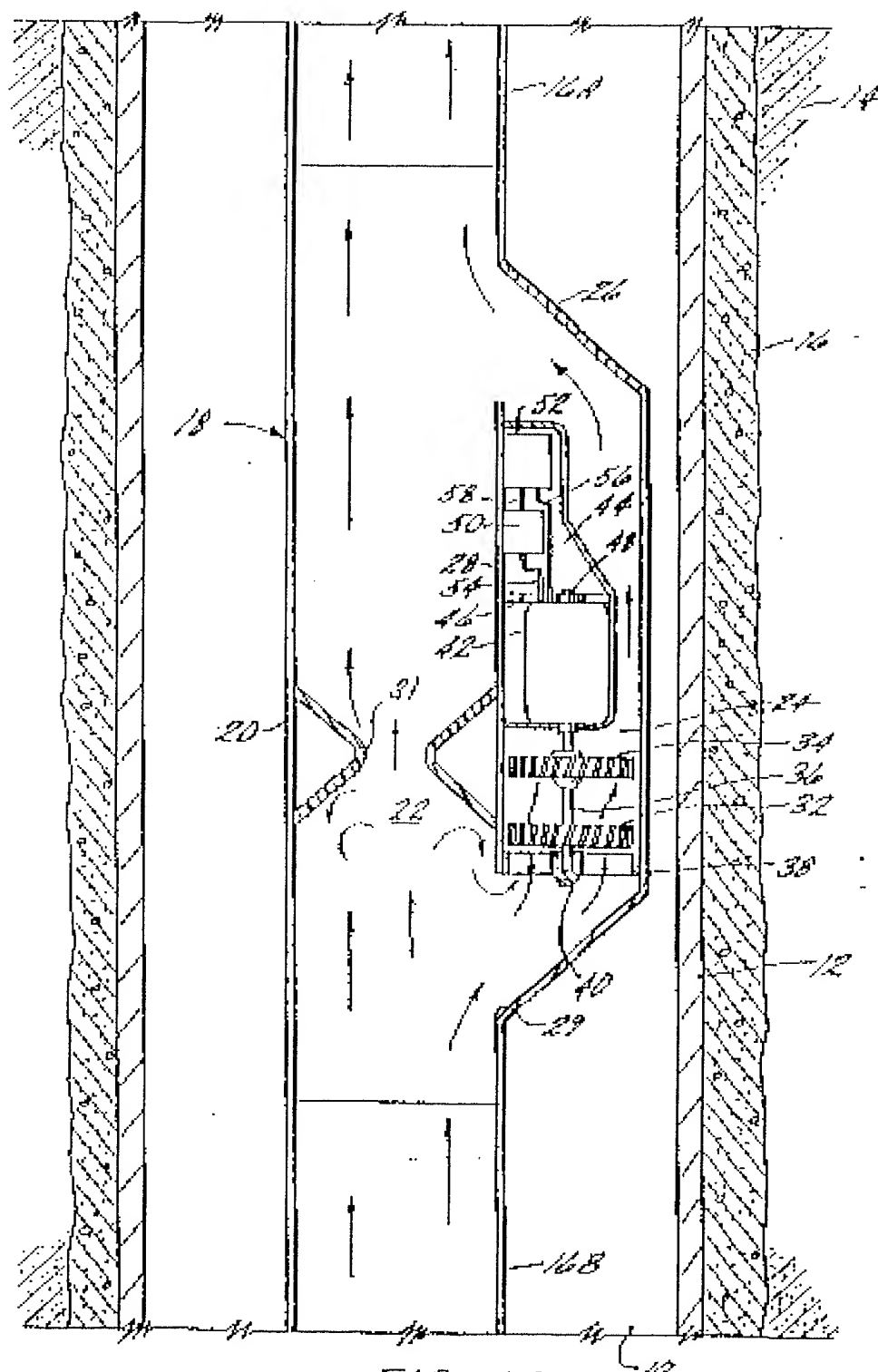


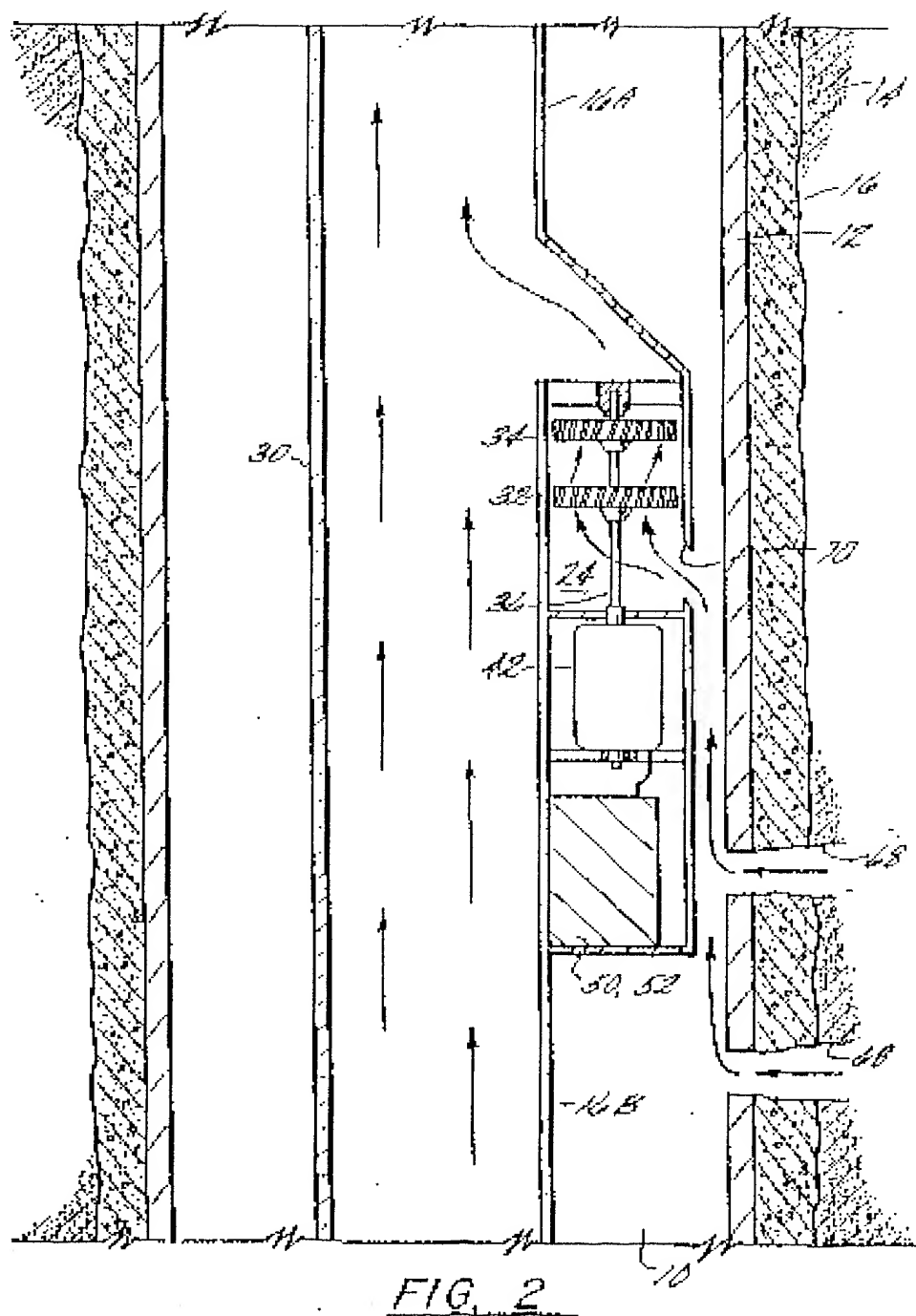
FIG. 1

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2/18



2/18



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4/18

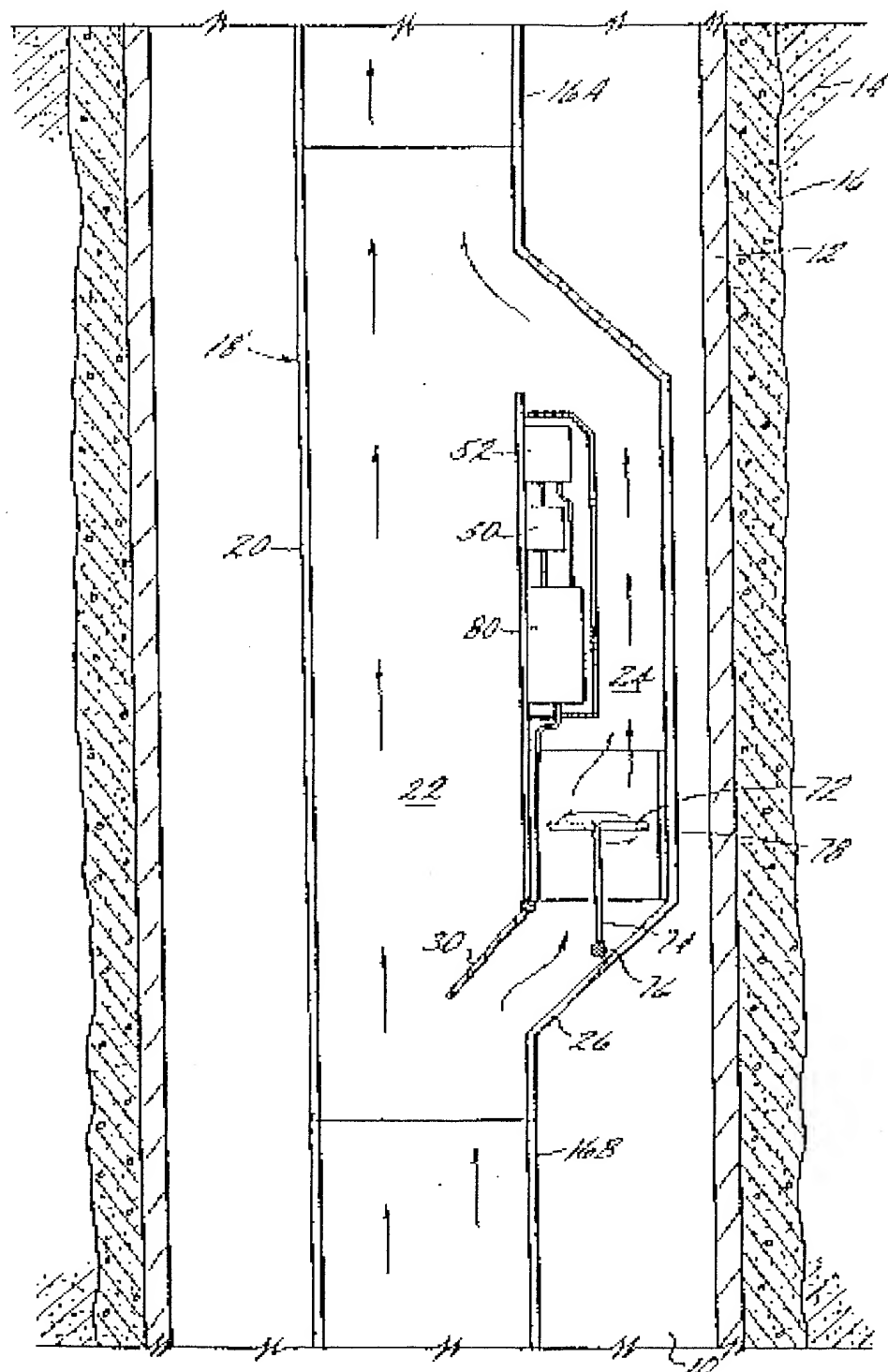
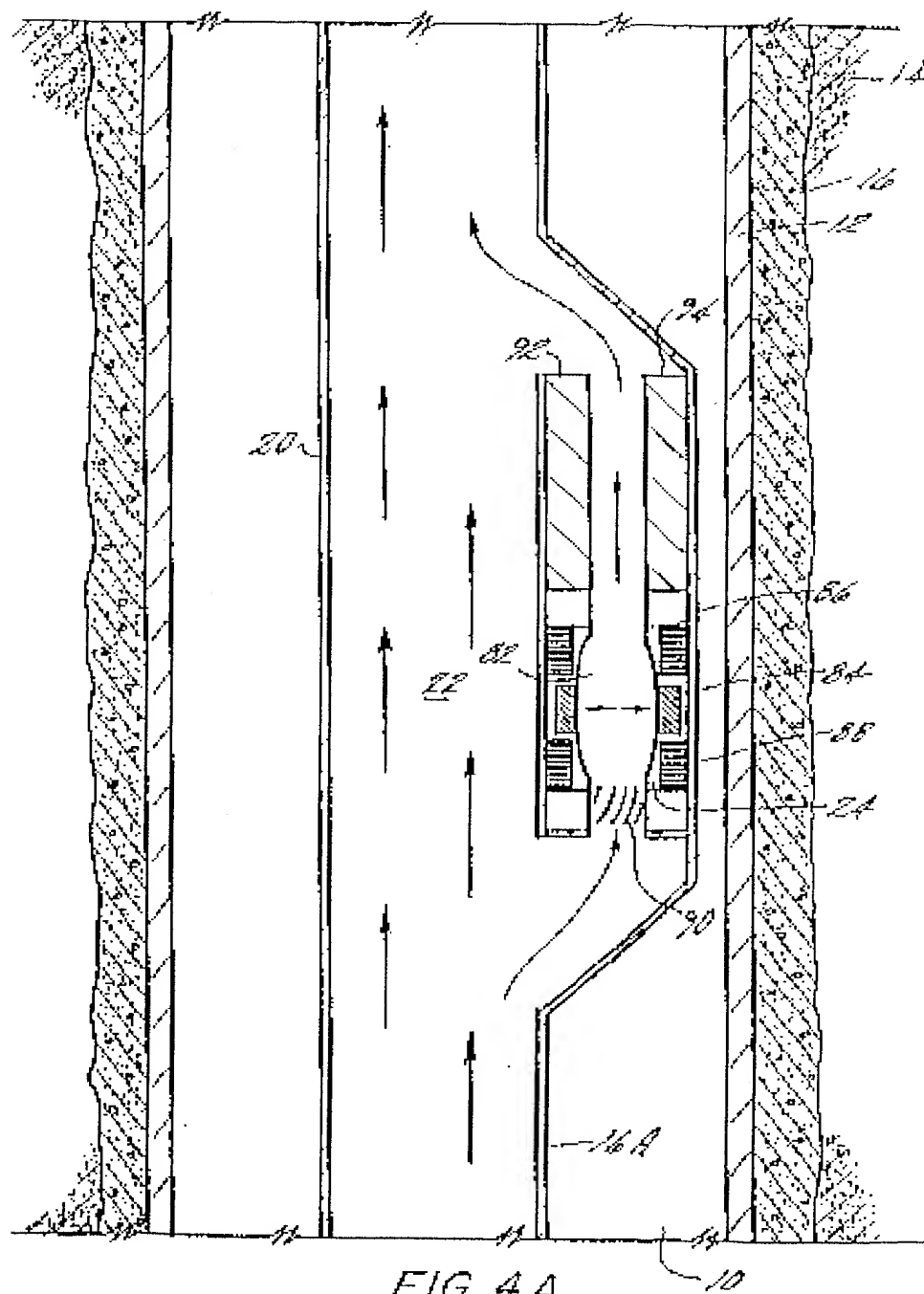


FIG. 3

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5/18



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6/18

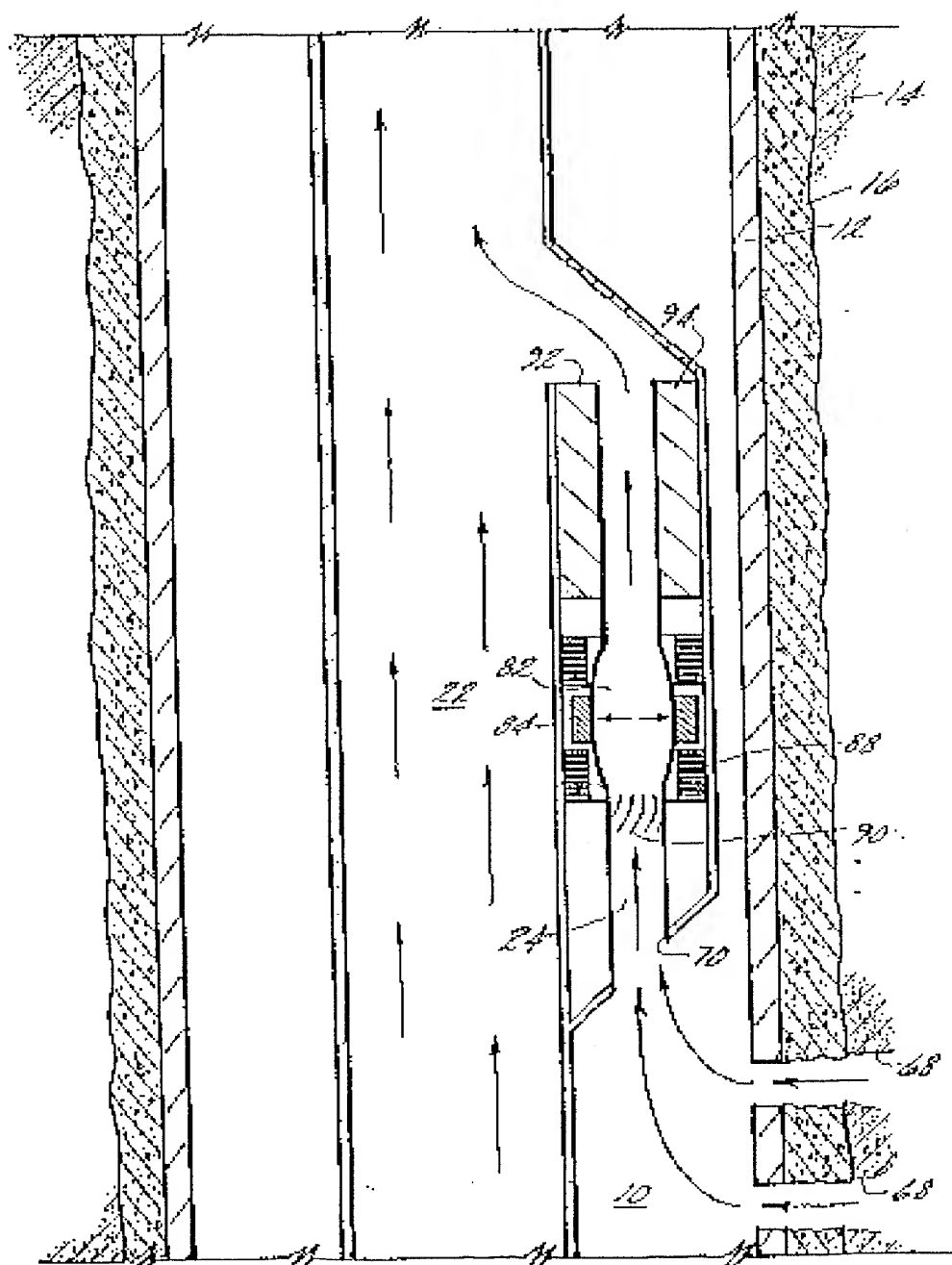


FIG. 4B

7/18

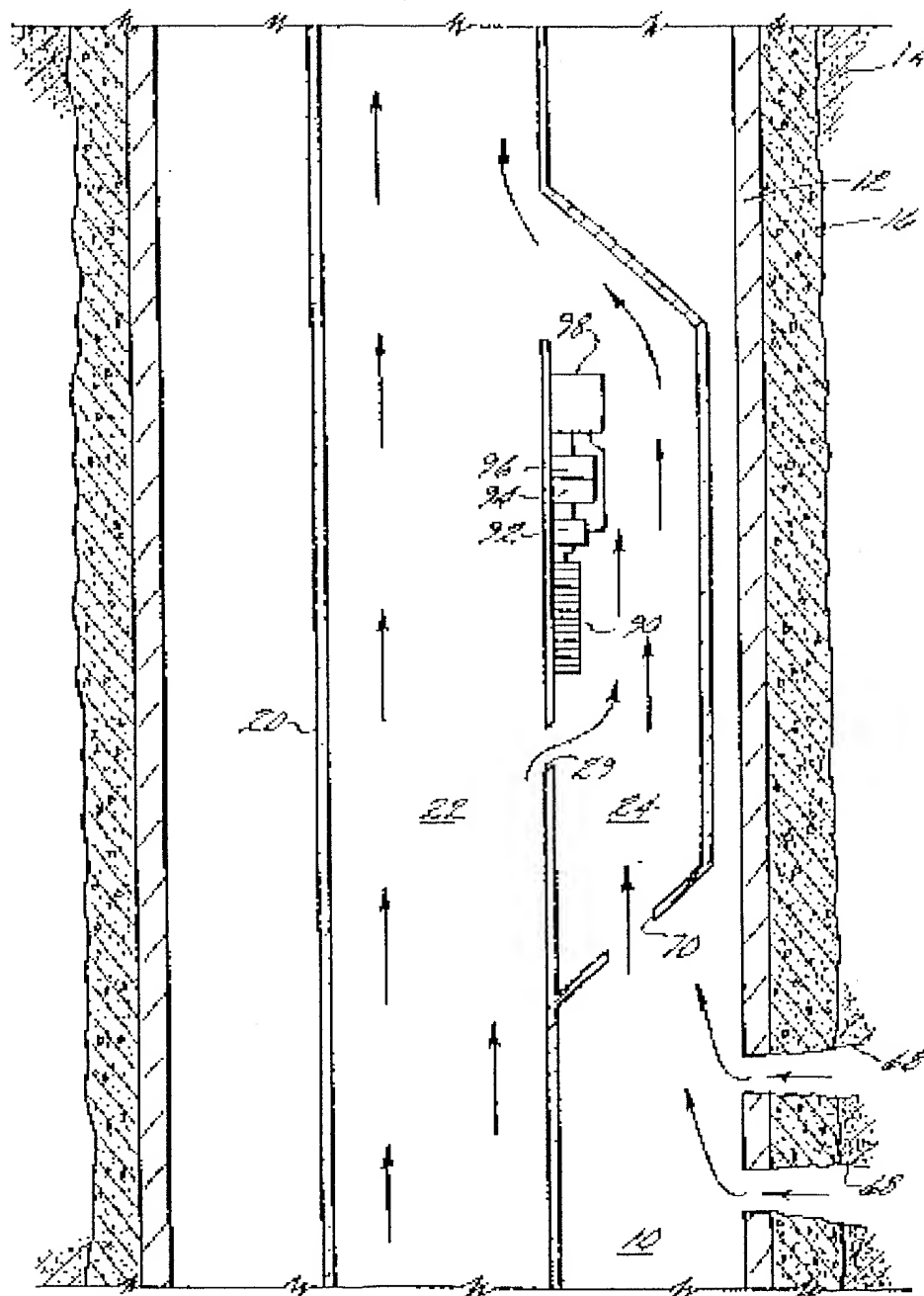


FIG. 5

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8/18

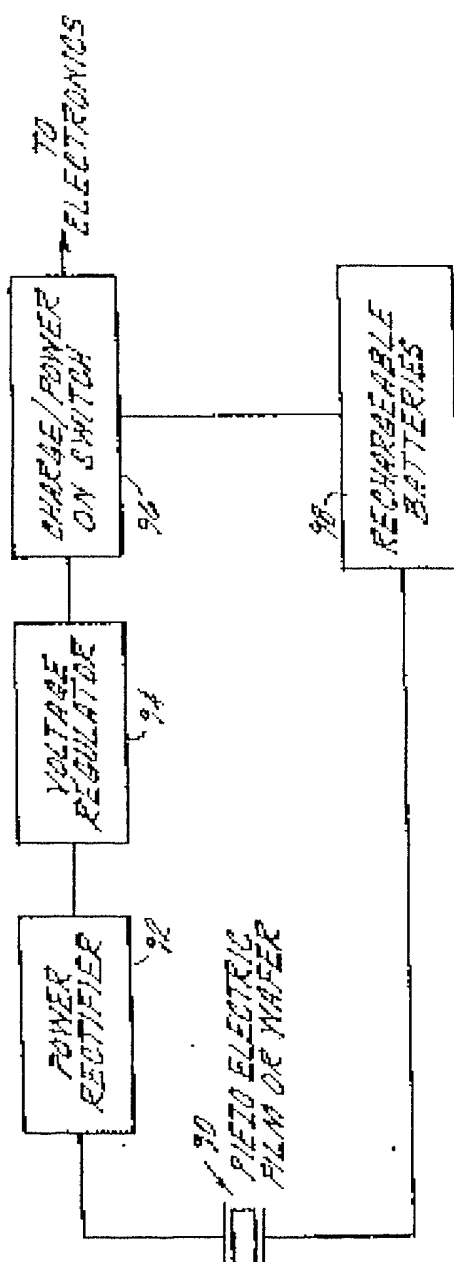


FIG. 6

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9/18

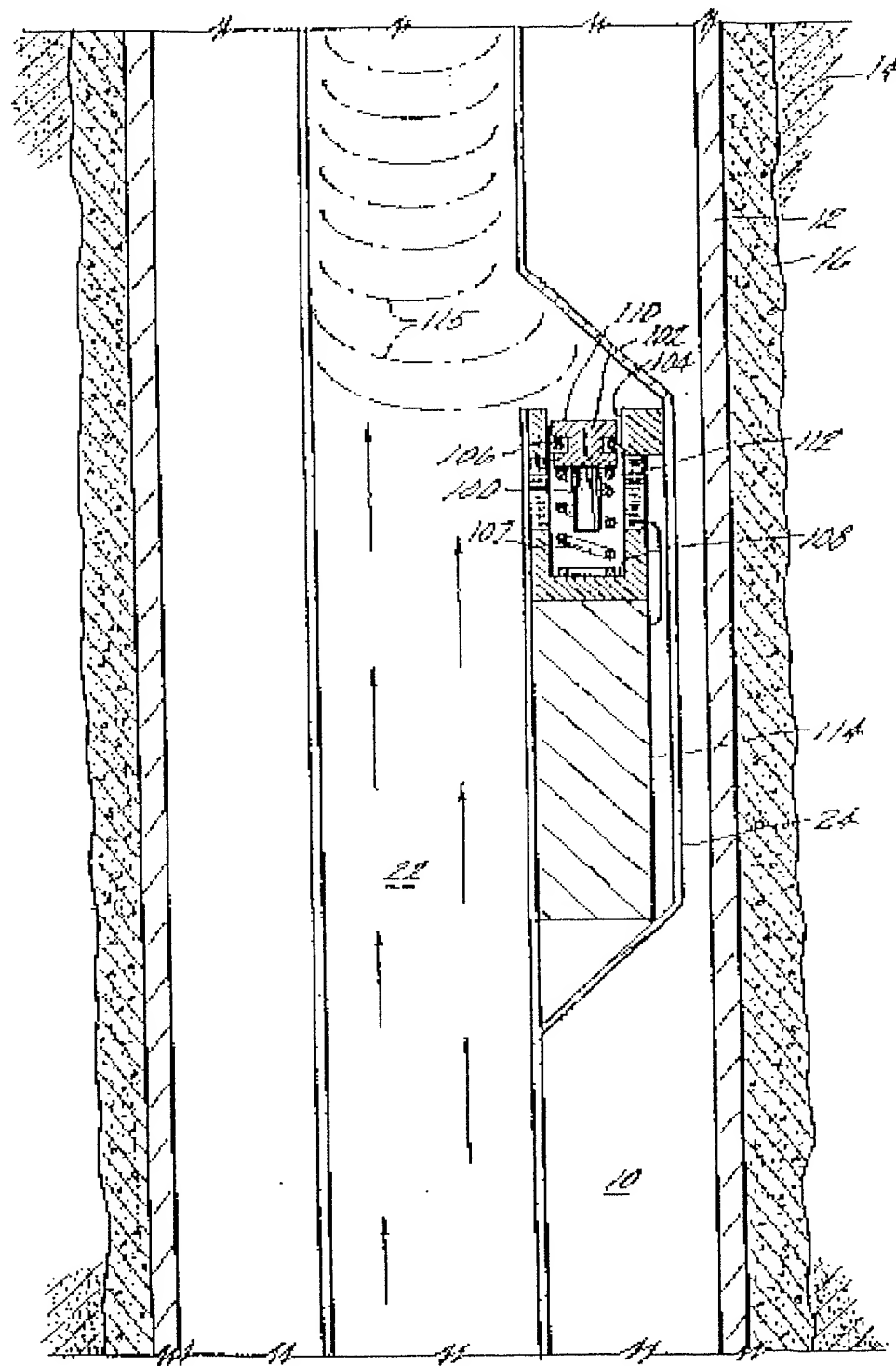
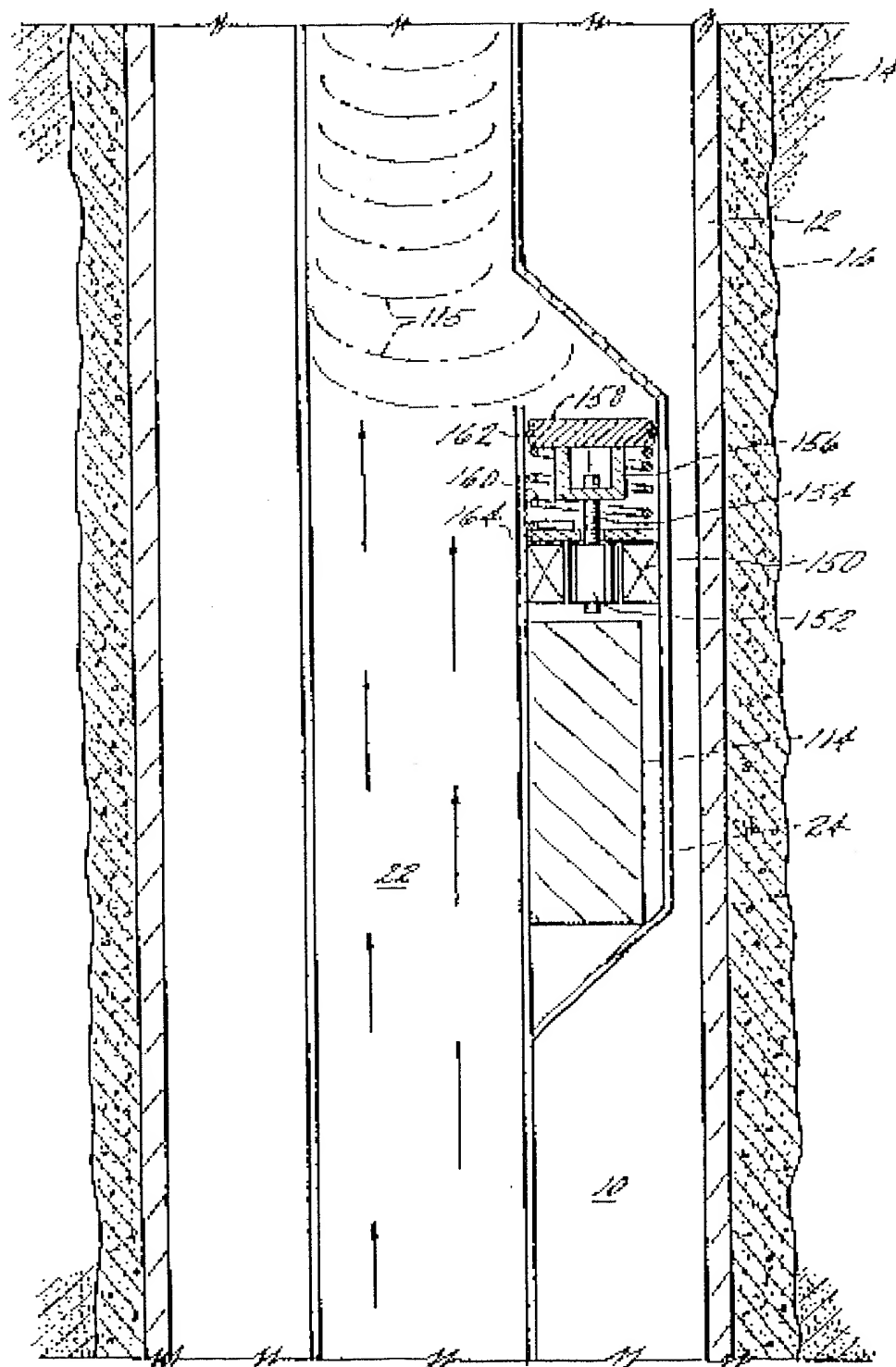


FIG. 7A

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10/18



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11/18

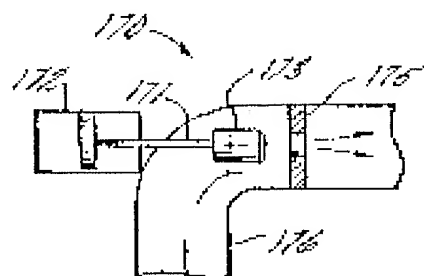


FIG. 7C

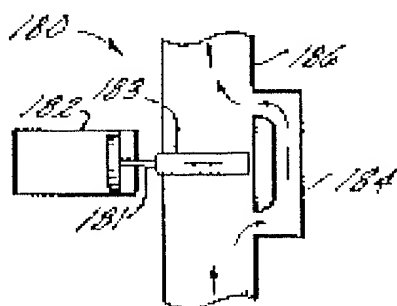


FIG. 7D

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12/18

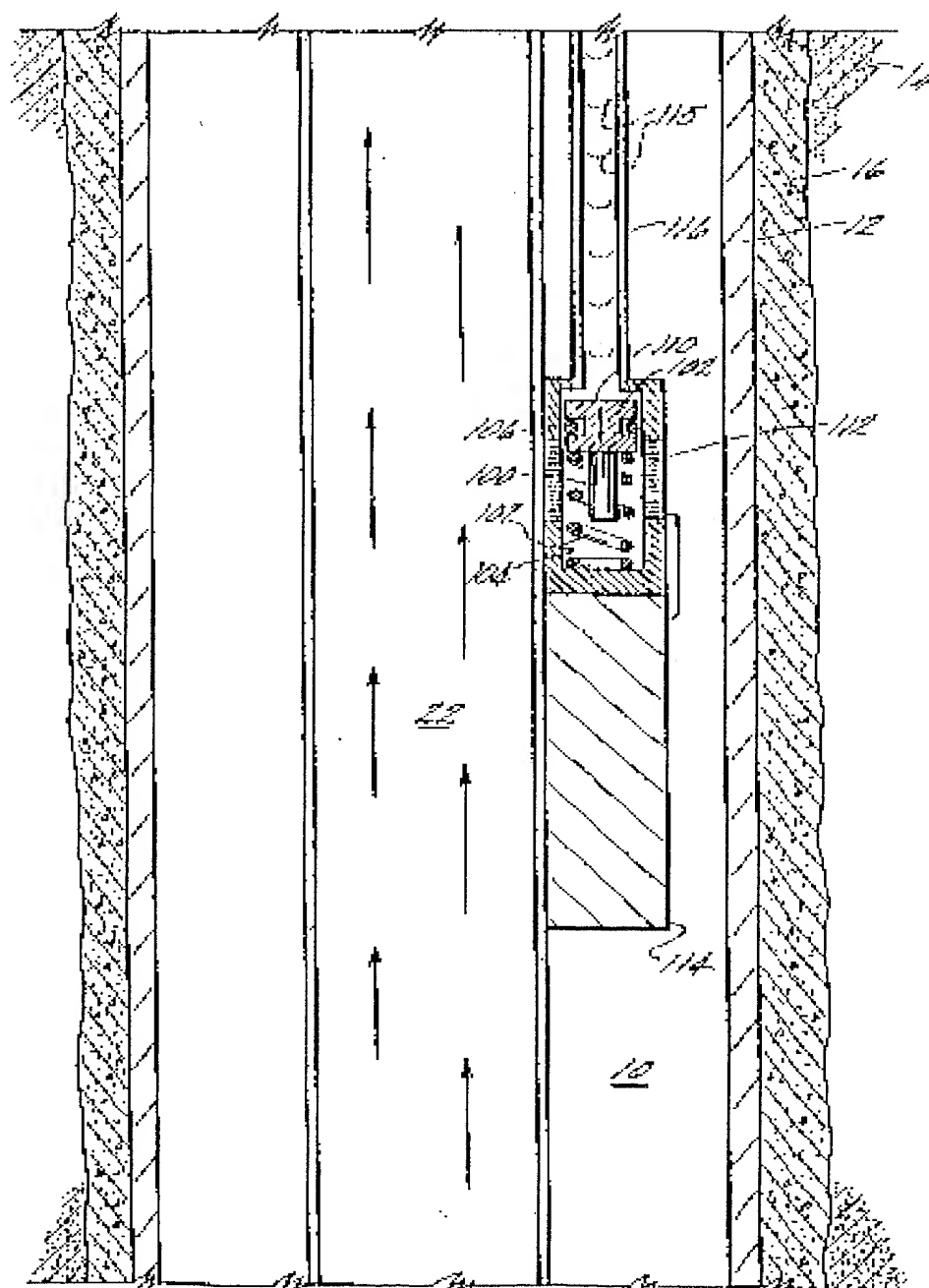


FIG. 8

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13/18

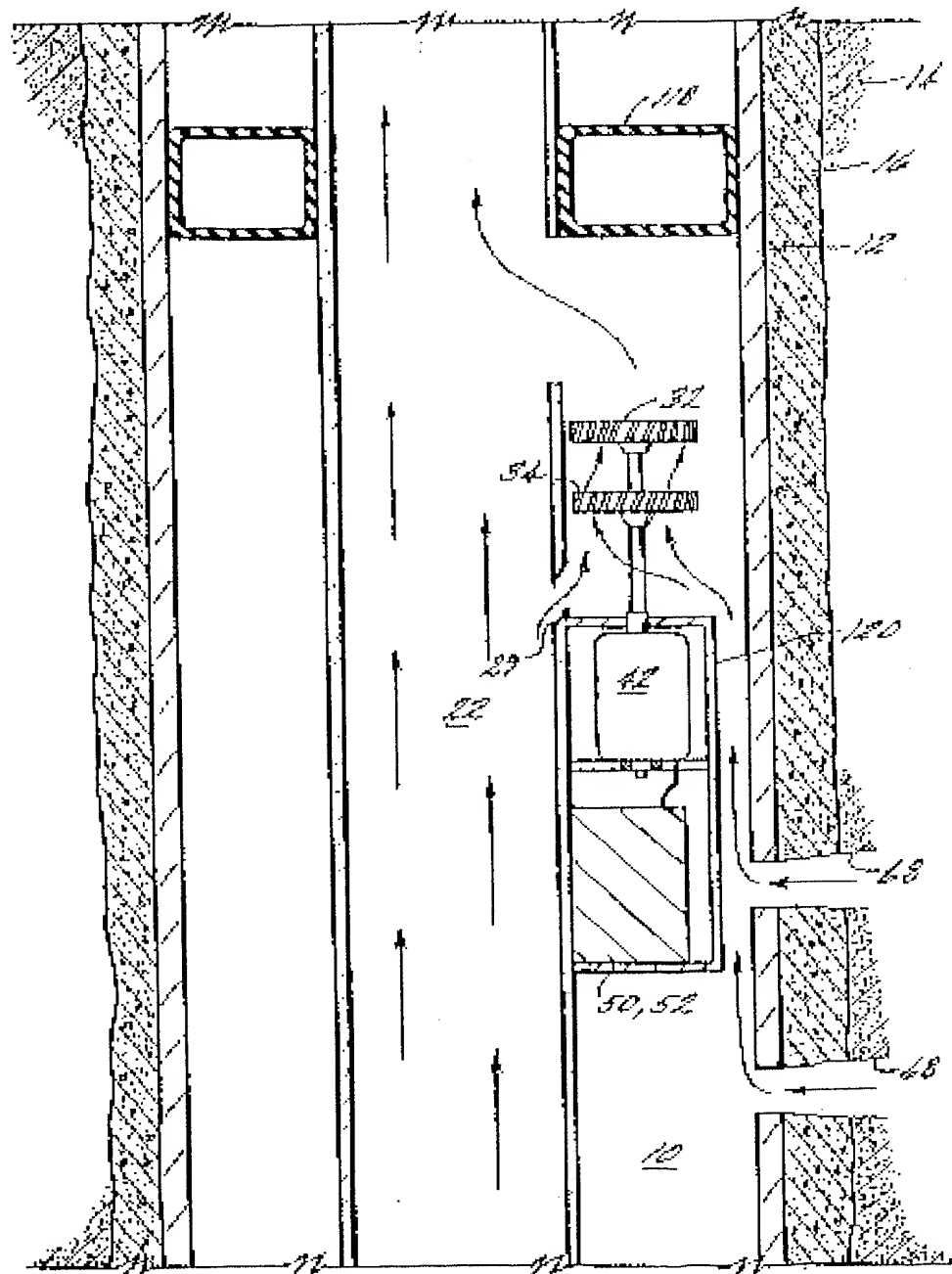
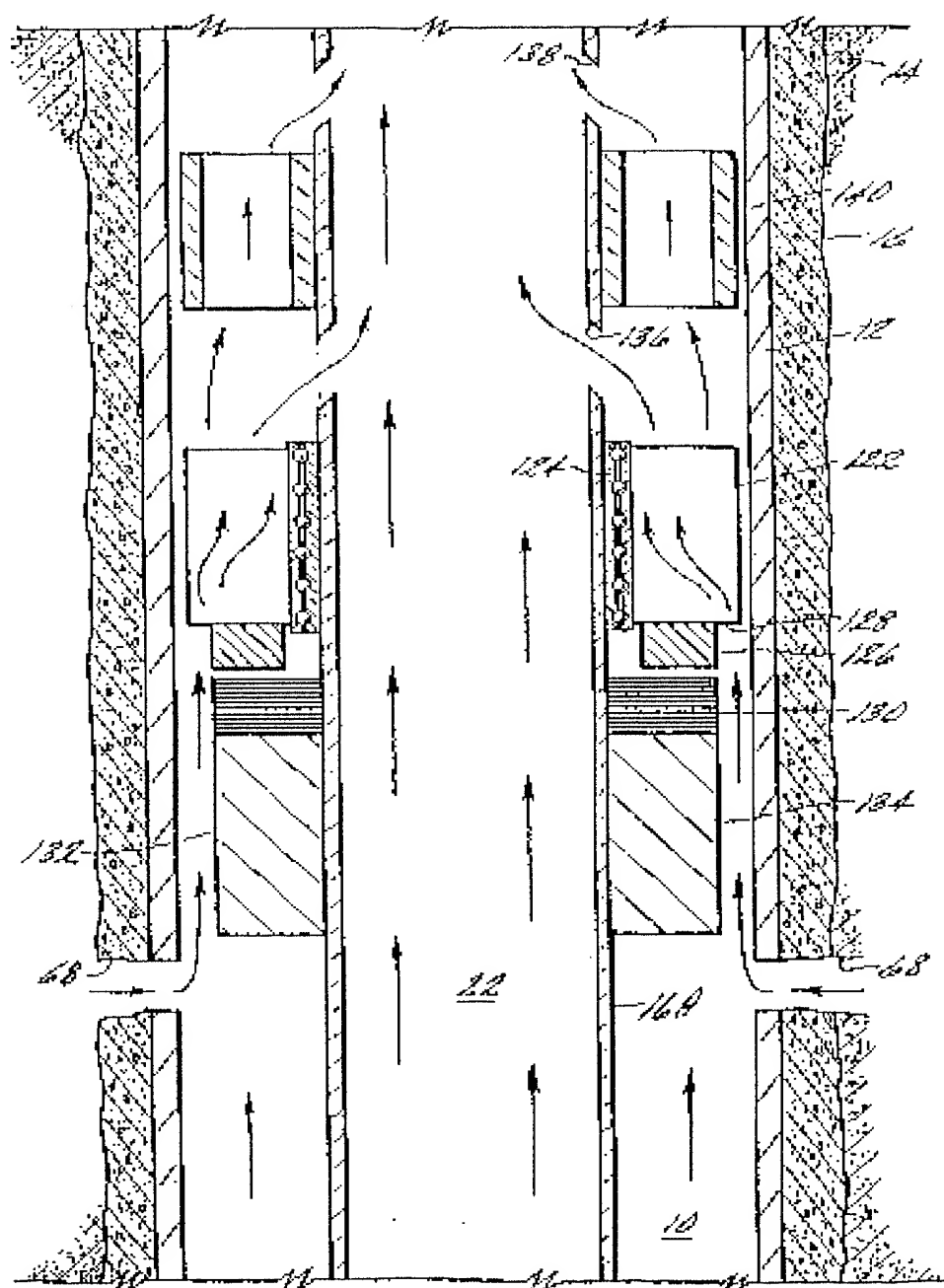


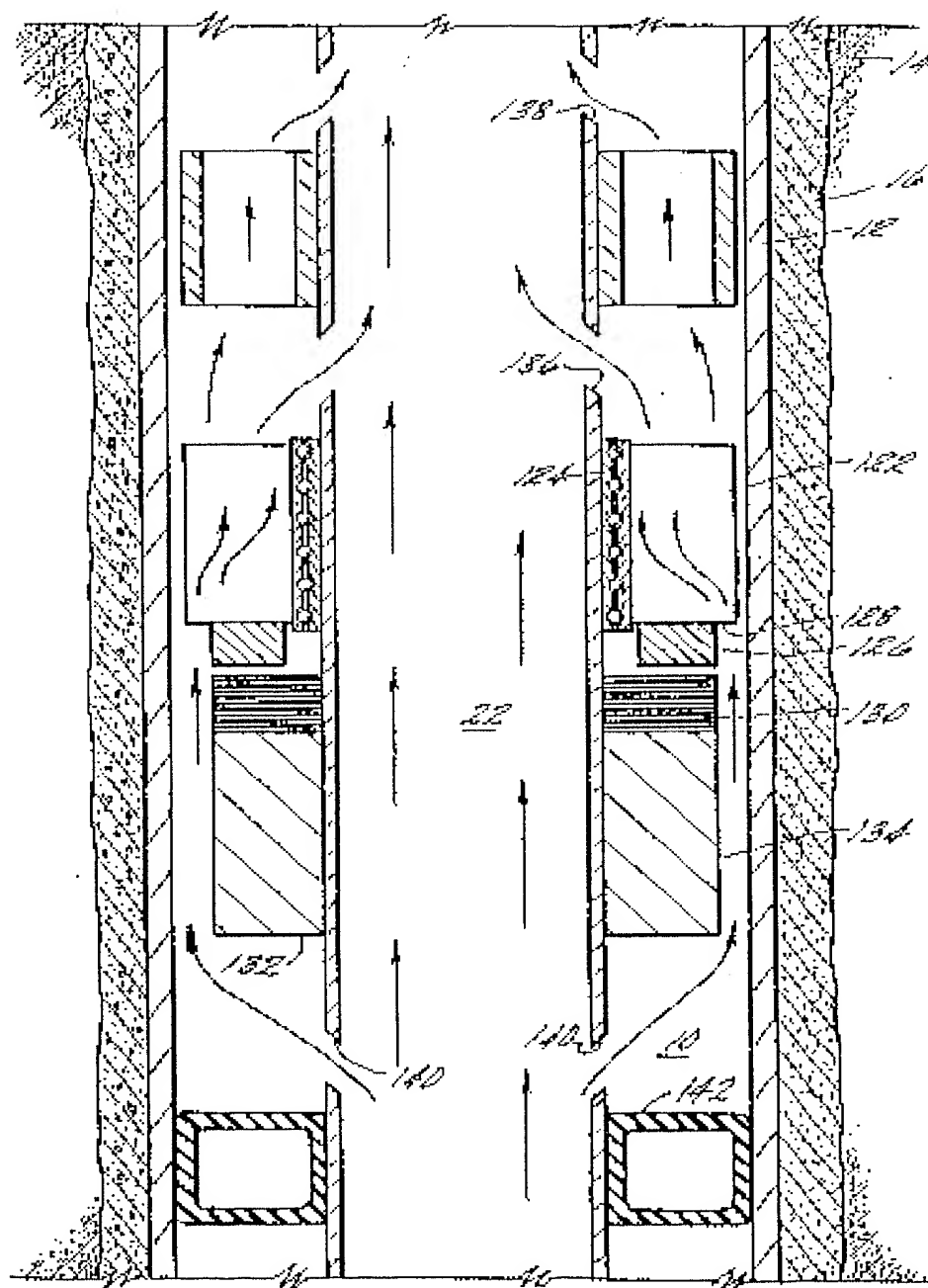
FIG. 9

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14/18

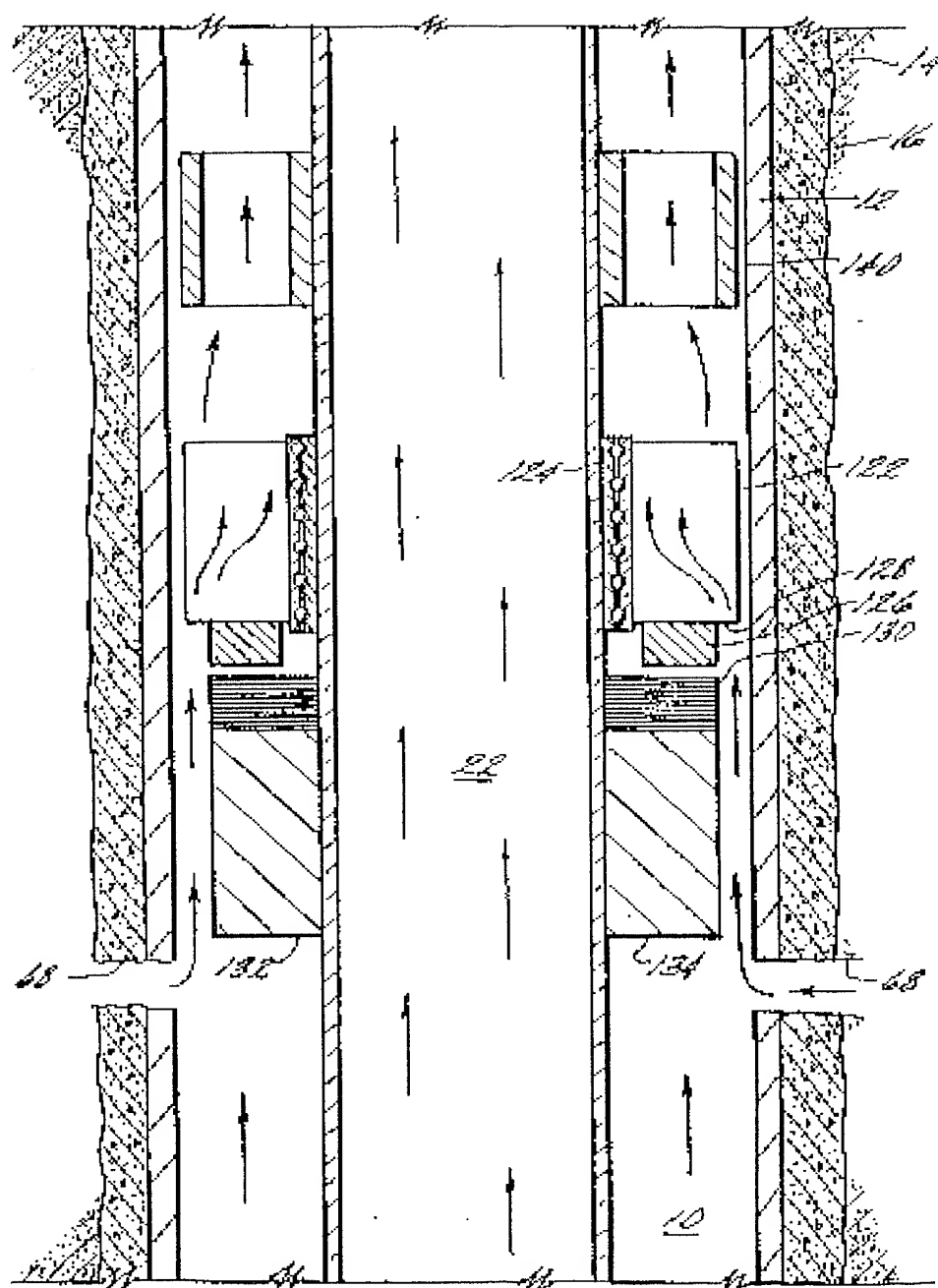


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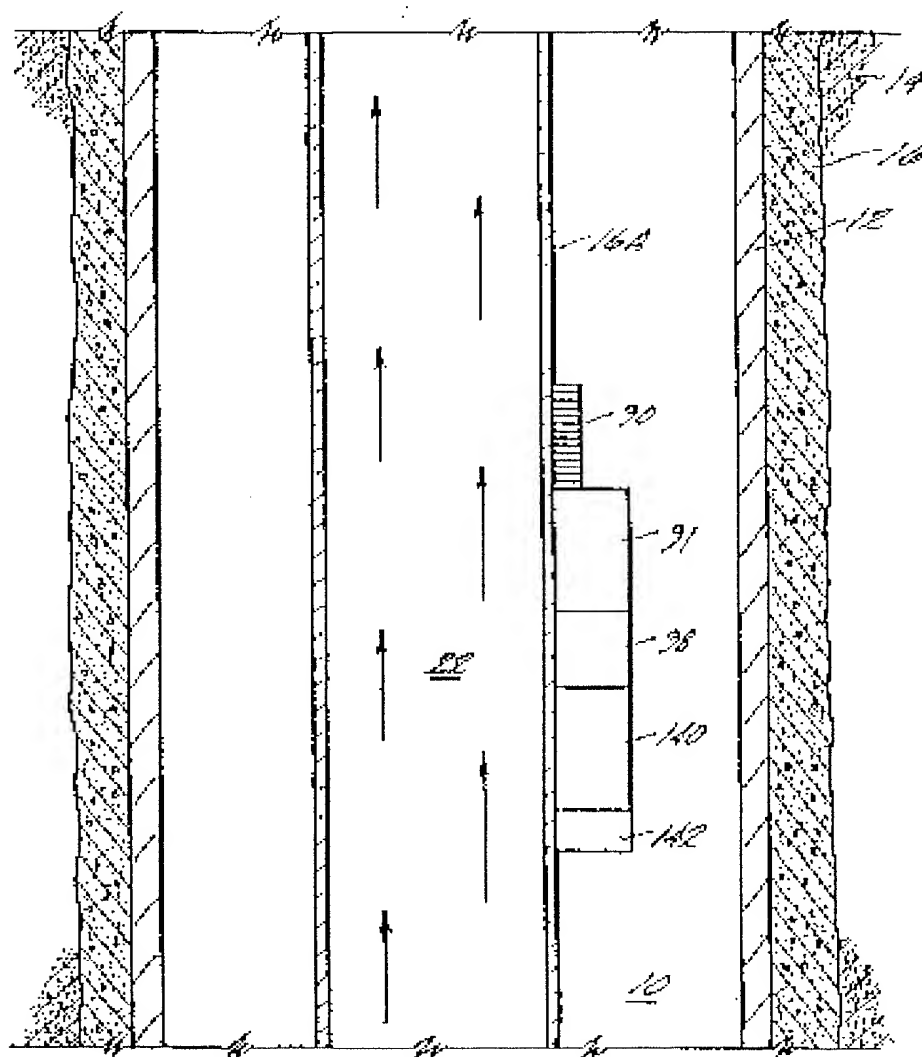


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16/18

FIG. 10C**SUBSTITUTE SHEET (RULE 26)**

17/18

FIG. 11

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18/18

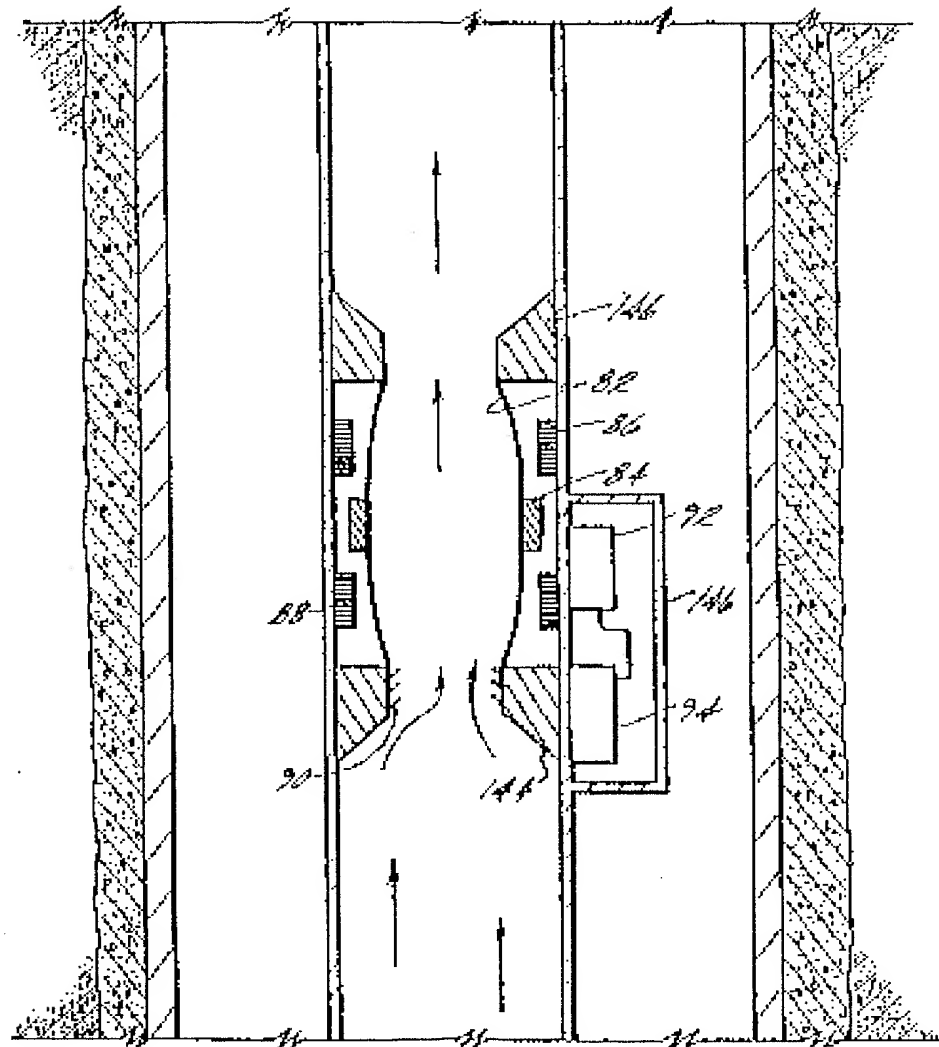


FIG. 12

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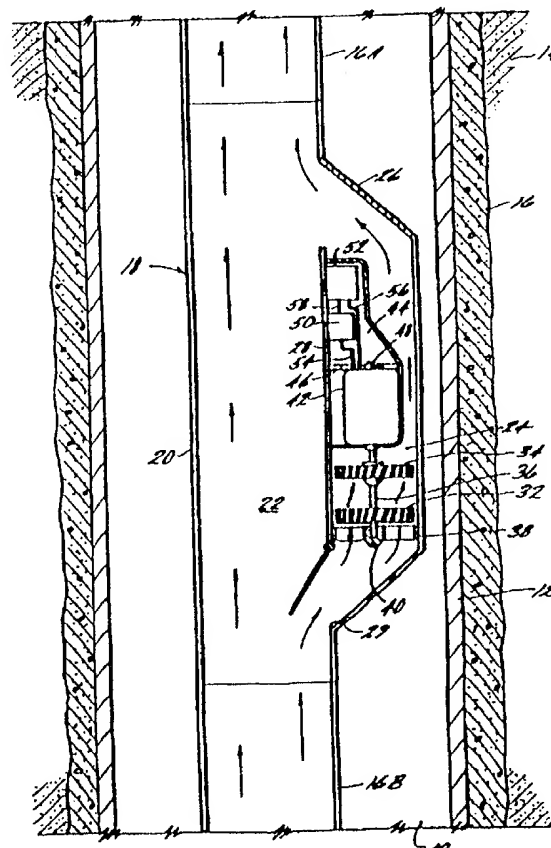
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E21B 41/00		A3	(11) International Publication Number: WO 97/01018
			(43) International Publication Date: 9 January 1997 (09.01.97)
(21) International Application Number: PCT/US96/10546			(81) Designated States: AU, CA, DE, DK, GB, NO.
(22) International Filing Date: 19 June 1996 (19.06.96)			Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(30) Priority Data: 60/000,469 23 June 1995 (23.06.95) US			(88) Date of publication of the international search report: 01 May 1997 (01.05.97)
(71) Applicant: BAKER HUGHES INCORPORATED [US/US]; 3900 Essex Lane, Houston, TX 77027 (US).			
(72) Inventors: TUBEL, Paulo; 118 E. Placid Hill, The Woodlands, TX 77381 (US). HOLCOMBE, Michael, Wayne; 1603 Carters Grove, Katy, TX 77449 (US). BAUGH, John, L.; 7519 Plumtree Court, Houston, TX 77095 (US). MULLINS, Albert, A., II; 18706 Arcaro Glen Court, Humble, TX 77436 (US). ROSS, Robert, Chapman; The Cottage, Lairshill, Newmachar, Aberdeen Shire AB5 0PX (GB).			
(74) Agents: CARSON, Matt et al.; Baker Hughes Incorporated, 3900 Essex Lane, Houston, TX 77027 (US).			

(54) Title: DOWNHOLE APPARATUS FOR GENERATING ELECTRICAL POWER IN A WELL

(57) Abstract

Electrical generating apparatus is provided which connects to the production tubing. In a preferred embodiment, this apparatus includes a housing having a primary flow passageway in communication with the production tubing. The housing also includes a laterally displaced side passageway communicating with the primary flow passageway such that production fluid passes upwardly towards the surface through the primary and side passageways. A flow diverter may be positioned in the housing to divert a variable amount of production fluid from the production tubing and into the side passageway. In accordance with an important feature of this invention, an electrical generator is located at least partially in or along the side passageway. The electrical generator generates electricity through the interaction of the flowing production fluid.



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INTERNATIONAL SEARCH REPORT

Int. l. Application No.
PCT/US 96/10546

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B41/00

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 080 224 A (SHELL INT.) 1 June 1983	1-4,9, 13,15, 19-24, 29-34, 40, 45-48,52
Y	see the whole document	16,17, 49,50, 53,54
X	& US 4 491 738 A (SHELL INT.) see the whole document	1,24,29, 40,48,52
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X	US 4 215 426 A (F. KLATT) 29 July 1980	1,2,8, 18,24, 29,40,41 35-39
A	see column 11 - column 12; figures 7-9	
X	US 3 342 267 A (G.S.COTTER) 19 September 1967 cited in the application see the whole document	1,2,18, 19
X	US 3 970 877 A (M.K.RUSSELL) 20 July 1976 cited in the application see the whole document	46
X	GB 2 096 373 A (GEARHART INDUSTRIES INC.) 13 October 1982 see figures 2,3	48
A	US 4 224 687 A (J.R. CLAYCOMB) 23 September 1980 see abstract	15-18, 49-55
A	US 4 515 225 A (SMITH INT.) 7 May 1985 see figure 4	11,12, 26-28
A	GB 2 230 288 A (TRANSBOR) 17 October 1990 see the whole document	1,8,41
A	US 2 898 088 A (R.L. ALDER) 4 August 1959 see the whole document	41-44
A	US 3 693 428 A (J.P. LE PEUVEDIC) 26 September 1972	1
A	US 3 448 305 A (J. RAYNAL) 3 June 1969	
A	US 4 518 888 A (C.J. ZABCIK) 21 May 1985 cited in the application	
A	EP 0 486 751 A (S.H.ELEKTRONIK GMBH.) 27 May 1992	
A	US 3 666 030 A (F.O. BOHN) 30 May 1972 cited in the application	
E	WO 96 24748 A (BAKER) 15 August 1996 see the whole document	1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/10546

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 80224 A	01-06-83	CA 1191531 A DE 3277825 A US 4491738 A	06-08-85 21-01-88 01-01-85
US 4578326 A	25-03-86	AU 2523384 A CA 1222341 A EP 0119912 A OA 7676 A US 4758483 A FR 2542322 A JP 1729084 C JP 2009627 B JP 59182844 A	13-09-84 26-05-87 26-09-84 23-05-85 19-07-88 14-09-84 29-01-93 02-03-90 17-10-84
US 4215426 A	29-07-80	NONE	
US 3342267 A	19-09-67	NONE	
US 3970877 A	20-07-76	GB 1462359 A	26-01-77
GB 2096373 A	13-10-82	AU 4134478 A CA 1124228 A CA 1150716 A CA 1145323 A CA 1166626 A DE 2852575 A FR 2410726 A GB 2009473 A,B GB 2096372 A,B GB 2094527 A,B GB 2094528 A,B NL 7811317 A,B, SU 1243633 A US 5390153 A US 4351037 A US 4866680 A US 4839870 A US 5150333 A US 4416000 A US 4520468 A	14-06-79 25-05-82 26-07-83 26-04-83 01-05-84 07-06-79 29-06-79 13-06-79 13-10-82 15-09-82 15-09-82 07-06-79 07-07-86 14-02-95 21-09-82 12-09-89 13-06-89 22-09-92 15-11-83 28-05-85

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/10546

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2096373 A		US 5113379 A	12-05-92
		US 5079750 A	07-01-92
		US 5182730 A	26-01-93
		US 4692911 A	08-09-87
US 4224687 A	23-09-80	DE 3022132 A	17-12-81
		GB 2076537 A,B	02-12-81
US 4515225 A	07-05-85	NONE	
GB 2230288 A	17-10-90	CA 2011972 A	13-09-90
		DE 4007907 A	27-09-90
US 2898088 A	04-08-59	NONE	
US 3693428 A	26-09-72	NONE	
US 3448305 A	03-06-69	NONE	
US 4518888 A	21-05-85	NONE	
EP 486751 A	27-05-92	DE 4037259 A	27-05-92
		AT 116711 T	15-01-95
US 3666030 A	30-05-72	NONE	
WO 9624748 A	15-08-96	US 5597042 A	28-01-97
		AU 4923896 A	27-08-96
		CA 2187432 A	15-08-96
		GB 2302113 A	08-01-97
		NO 960519 A	12-08-96